# Complete Arterial Revascularization With the Internal Thoracic Arteries

Robert Dion

More than 25 years ago, Green,[1] the pioneer of the clinical application of the internal thoracic artery (ITA) prophesied, "The ITA pedicled graft carries its homeostatic milieu with it." More recent reports have unveiled some of the outstanding characteristics of ITA grafts, namely, physiological adaptability[2-7] and resistance to atherosclerosis resulting from remarkable qualities, such as superior prostacyclin secretion,[8] integrity of the internal elastic lamina, and the rarity of muscular cells in the media, mostly consisting of elastin.[9,10] Indeed, the long-term patency rate of ITA grafts has been proved far superior to that of saphenous vein grafts.[11-14] Technical developments, such as sequential and bilateral grafting, construction of diamond-shaped anastomoses, and directing the right ITA through the transverse sinus,[15] have enabled surgeons to reperfuse an increasing number of coronary vessels with pedicled ITA grafts. The additional use of free ITA grafts, particularly when a free right ITA (RITA) graft is anastomosed to the pedicled left ITA (LITA) graft ("T" ITA graft), allows a total arterial revascularization of the whole myocardium in selected patients.

## No ITA-Linked Exclusion Criteria

Unlike many investigators,[16-18] we have not taken into account the adequacy of ITA free cut-end flow, possible caliber discrepancy, the lack of a high-grade proximal coronary stenosis, or the amount of myocardium revascularized, even before sequential grafting.[19] However, we have not hesitated intraoperatively to add a saphenous vein graft in parallel to an ITA graft whenever ITA flow insufficiency[16,18,20,21] is suspected (2% of all ITA grafts).

We are convinced that this approach allows more patients to benefit from complex ITA grafting than if we respected the above-mentioned exclusion criteria. We only insist on obtaining a careful injection of both ITA arteries at the end of the preoperative cardiac catheterization.

## ITA Grafting Strategy

Similar to Rankin et al,[17] we anastomose ITAs "not so much to the best vessels, but to the best myocardium" and we always try to keep the ITA grafts pedicled. Our preferred grafting strategy (Fig 8) consists of directing LITA to the left anterior descending (LAD)-diagonal area and RITA to the remaining most-dominant diseased coronary vessel(s). This includes directing RITA through the transverse sinus if one or more circumflex (Cx) branches are the targets. In recent years, the right gastroepiploic artery (GEA) was preferred to RITA for grafting of the distal right coronary artery (RCA) and/or its branches.

There are, in our view, three explanations for the disappointing patency rates of RITA anastomosed to the distal RCA and its branches. First, tension may develop on the RITA, which is attempting to reach very distal sites on the RCA or posterior descending artery (PDA); indeed, the right side of the heart, around which RITA is coursing towards distal RCA, may considerably vary in volume postoperatively under various physiological conditions. Secondly, there is often a marked discrepancy between the calibers of the distal RITA and the distal RCA, the latter of which is still frequently more than 2 mm. Also, the wall thickness of the distal RCA often requires a relatively longer arteriotomy, which adds to the technical difficulty of matching the two vessels at the site of the anastomosis.

Accordingly, at the present time, we do not attempt to reach RCA much further than the acute margin of the heart when using RITA, and, in this situation, we keep the length of RITA as short as possible; its flow will be optimized because of the greater distal caliber and the decreased conduit resistance. By applying these rules, we have been encouraged to find that the patency rates of RITA anastomosed to RCA, which initially were somewhat disappointing (83.2%),[19] have returned to the level of those of RITA to LAD and to Cx arteries (Table 1).[22] If a rather distal Cx artery branch needs to be grafted and, provided that there is no significant diagonal artery to be reperfused, LITA is more easily directed to the Cx branch(es); RITA is then anastomosed to the LAD area (Fig 9). However, we prefer to avoid the construction of a sequential RITA graft to LAD and diagonal arteries successively, because of the risk of the LAD stealing the (graft) blood (Fig 24) and because LAD is often somewhat deeper into the epicardium, which could lead to the seagull-wings effect (Fig 25) at the site of the side-to-side diamond-shaped anastomosis between RITA and LAD. Consequently, in the presence of a significant diagonal artery, I prefer to

**TABLE 1. Angiographic Patency of ITA Anastomoses***

| | Pedicled Left ITA | | | Pedicled Right ITA | | |
|---|---|---|---|---|---|---|
| | Restudied | Patent | (%) | Restudied | Patent | (%) |
| LAD | 232 | 225 | 96.9 | 42 | 40 | 95.2 |
| Cx | 45 | 43 | 95.6 | 90 | 86 | 95.2 |
| RCA | — | — | — | 31 | 29 | 93.5 |
| Total | 277 | 268 | 96.7 | 163 | 155 | 95.1 |
| | | | NS | | | |
| LAD *v* Cx: NS | | | | LAD *v* Cx<br>LAD *v* RCA<br>Cx *v* RCA | | NS |

*Correlation with grafted coronary vessel and with type of conduit. Patency rates were compared using the likehood ratio statistic $G^2$.
Abbreviation: NS, not significant.
Reprinted with permission.[22]

construct a sequential diagonal-LAD (D-LAD) graft with LITA to anastomose the free RITA to the Cx branch(es), and to reimplant the RITA graft into the LITA pedicle, as illustrated later (Fig 10). The same principle applies if an ITA graft has to be used as a free graft because of injury at harvesting.

## Keep ITA Pedicle as Short as Possible and Protect It From the Lung and the Sternum

The longer the ITA pedicle is, the smaller its distal caliber, and the lower the distributed flow. Furthermore, the part of the ITA that is near and beyond its distal bifurcation is known to be more muscular and less elastic; therefore, it is more prone to develop spasm and atherosclerosis. It is important to minimize the length of ITA between its origin from the subclavian artery and the first distal anastomosis. In our experience, we achieve this by opening the ipsilateral pleura (particularly on the left side) and by incising vertically the pleura and the pericardium down to the phrenic nerve (Fig 11). Other advantages of this maneuver are that the ITA pedicle then lies under the lung and away from the sternum, and that the pericardium, prolonged by the pleural fat, can easily be approximated at the end of the procedure.

## Appropriate Disposition of ITA Anastomoses Over the Myocardium

Coronary artery disease may progress, and therefore arterial grafts should be evenly distributed over the myocardium. Grafting two (or three) adjacent coronary vessels with two different arterial grafts should be prevented by constructing a sequential graft with one pedicle. Also, the anastomoses should be placed distal to any significant lesion, especially on the LAD, and again, sequential grafting must be considered.

## Free ITA Grafts

In a recent review of our first 124 free ITA grafts,[23] their patency rate at 15 months (86.4%) was significantly lower than that of pedicled ITA grafts (100%). We then try to restrict the use of free grafts and, if we have no alternative, we anastomose them to the other pedicled ITA (Fig 10, 29 right), as reported by Tector et al,[24] Barra et al,[25] and Calafiore et al.[26]

## Myocardial Protection

From 1985 to 1988, we used systemic hypothermia (25 to 28°C) and intermittent cold crystalloid (St. Thomas) antegrade cardioplegia with intermittent topical cooling. From 1988, we applied only a moderate systemic hypothermic (30 to 32°C) and performed a combined intermittent antegrade and retrograde cold crystalloid (St. Thomas) cardioplegia. Towards the end of 1993, we used systemic normothermia and continuous retrograde warm-blood cardioplegia in 40 patients. We abandoned that method because of technical hindrance during the anastomoses and because of technically unexplained and frequent postoperative enzymatic moderate elevation. From 1994, we converted to systemic normothermia and to intermittent antegrade warm-blood cardioplegia, as advocated by Calafiore et al.[27] Used in more than 400 consecutive isolated coronary artery bypass graft procedures, this method seemed to yield excellent results. In January 1996, we launched a prospective randomized study comparing both methods (cold crystalloid antegrade + retrograde and hypothermia *v* warm-blood intermittent antegrade and normothermia) with regard to their systemic, neurological, and myocardial effects. I believe that this study will underline the systemic and myocardial advantages of normothermia as we have experienced them during our pilot study: decreased use of inotropes and duration of cardiopulmonary bypass; very low postoperative level of cardiac enzymes; and decreased incidence of reoperation for bleeding and of pulmonary complications, leading to a shortening of the intensive care unit stay and to reduced transfusion requirements.

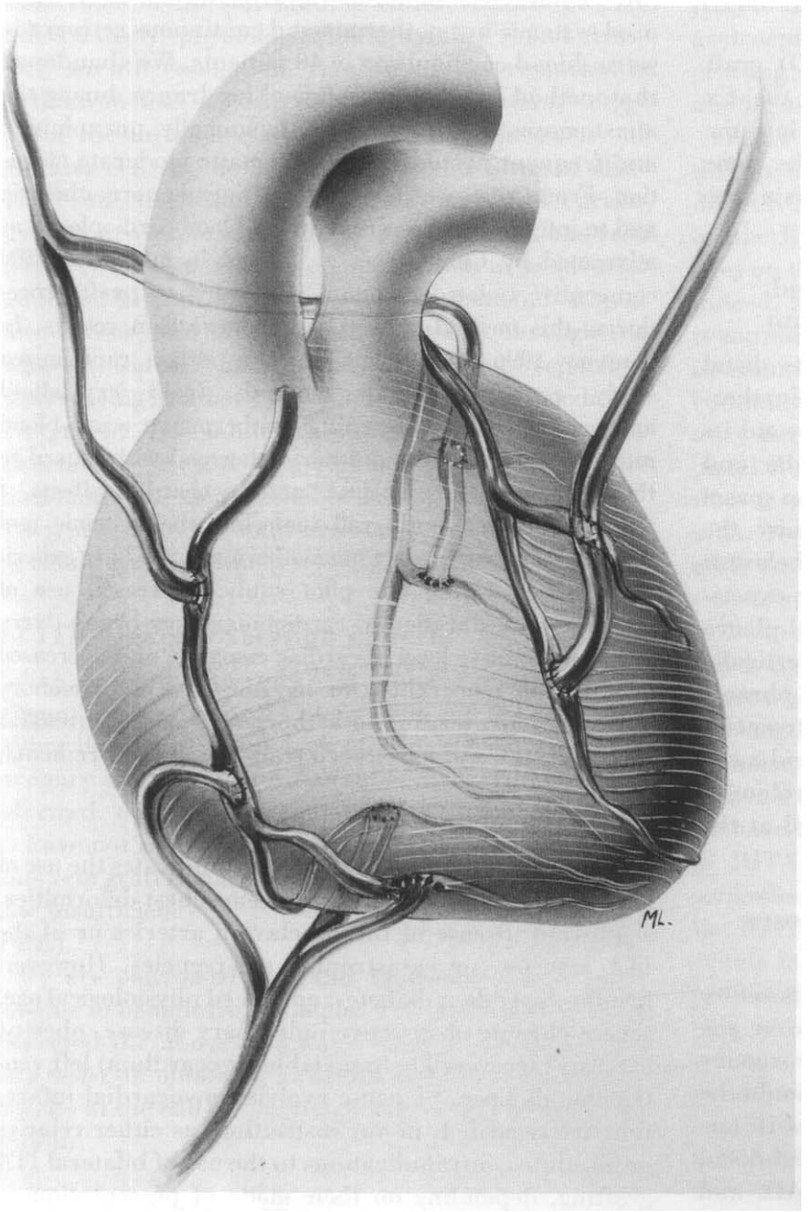
## Patient Selection

Nearly no situation exists that contraindicates the use of a single ITA graft aside from extreme chest deformities, significant disease of the subclavian arteries or of the ITA arteries, or catastrophic emergencies. However, insulin-dependent diabetes, advanced physiological age, severe chronic obstructive pulmonary disease, obesity, extensive irreversible (nonviable myocardium) left ventricular damage, or acute evolving myocardial infarction are regarded, in our institution, as either relative or absolute contraindications to the use of bilateral ITA grafting, depending on their mode of presentation or association. We prefer to say that a patient less than 65 years of age should normally benefit from complex arterial grafting, whereas a patient more than 65 years of age has to somehow "deserve" it. Common sense must guide the decision in borderline conditions.

### Sequential IMA Grafting

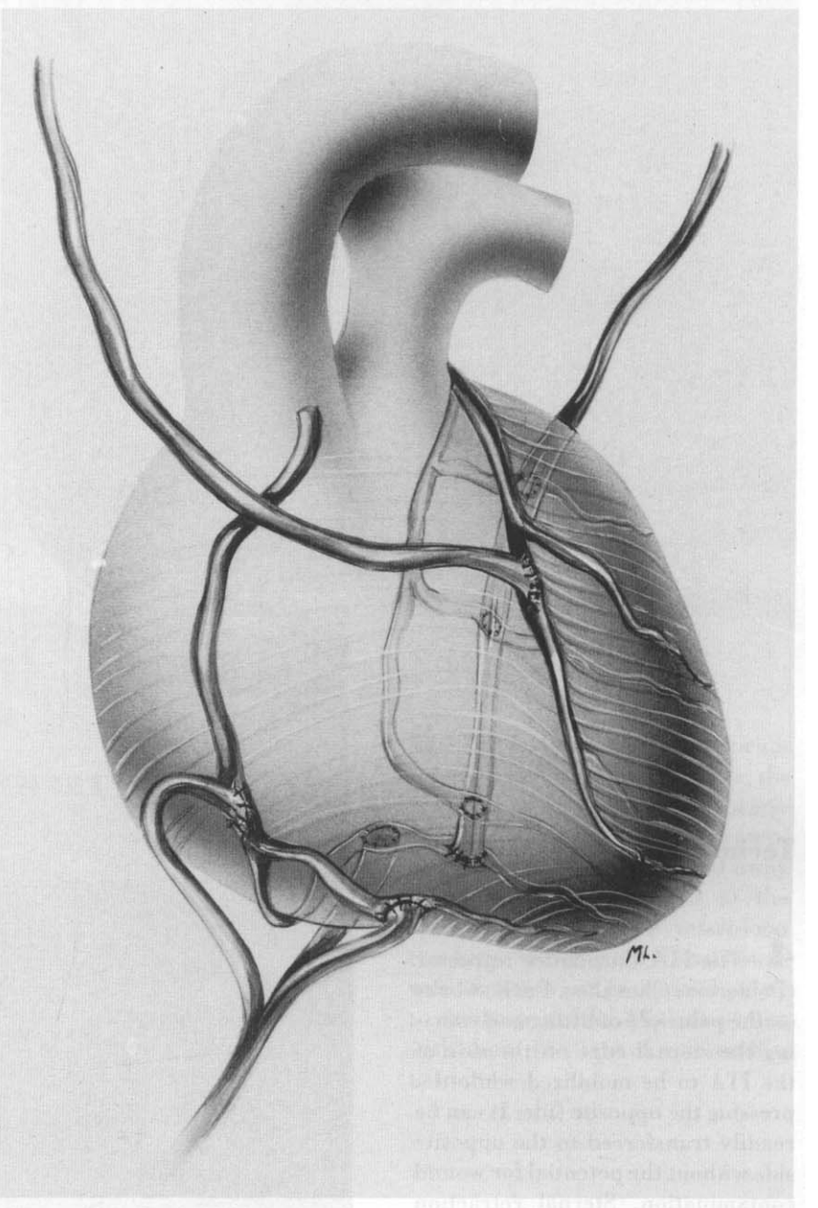
Sequential grafting is essential if a pedicled ITA graft is to be optimized. Side-to-side anastomoses may be constructed either longitudinally or in a diamond-shaped fashion. The ITA is approached through a generous 2-cm longitudinal incision in the ventral aspect of the pedicle to prevent undesirable angulation caused by the thickness of the pedicle. When sequential anastomoses are close to each other (<2 cm), we prefer to incise the ventral aspect of the pedicle all along between the two anastomoses. We prefer to place the distal anastomosis on the most dominant coronary vessel. As mentioned previously, we insist on keeping ITA pedicles as short as possible.

### Our Preferred Grafting Strategy



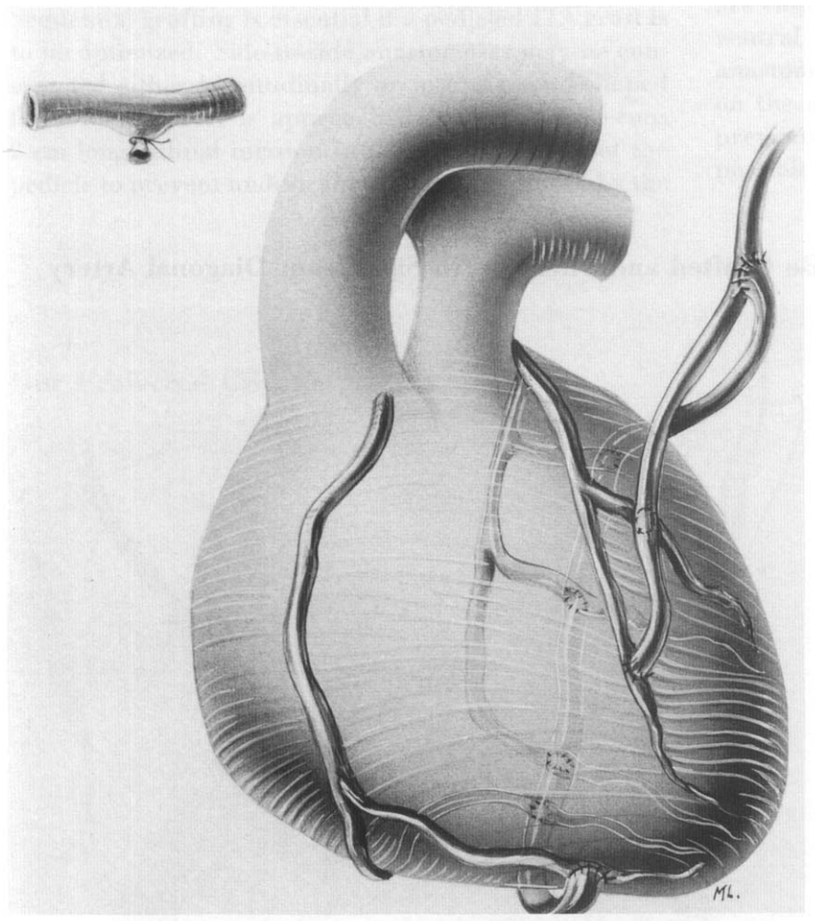

**1** Our preferred grafting strategy consists of directing LITA to the LAD-diagonal area and RITA to the remaining most dominant diseased coronary vessel(s). This includes directing RITA through the transverse sinus if one or more Cx branches are the targets. In recent years, the right GEA was preferred to RITA for grafting of the distal RCA and/or its branches.

## If a Rather Distal Cx Branch Needs to Be Grafted and There is No Significant Diagonal Artery



**2** If a rather distal Cx artery branch needs to be grafted and, provided that there is no significant diagonal artery to be reperfused, LITA is more easily directed to the Cx branch(es); RITA is then anastomosed to the LAD area. However, I do not like to construct a sequential RITA graft to LAD and diagonal arteries successively because of the risk of steal of blood to the LAD (Fig 24) and because LAD is often somewhat deeper into the epicardium, which could lead to the seagull-wings effect (Fig 25) at the site of the side-to-side diamond-shaped anastomosis between RITA and LAD. In this configuration, the postero-lateral branch (and sometimes the PDA) of RCA can be reached by LITA. Therefore, a deep vertical incision must be made into the left mediastinal pleura and pericardium down to the left phrenic nerve (Fig 11).

## If a Rather Distal Branch and a Significant Diagonal (Not Intermediate) Need to Be Grafted

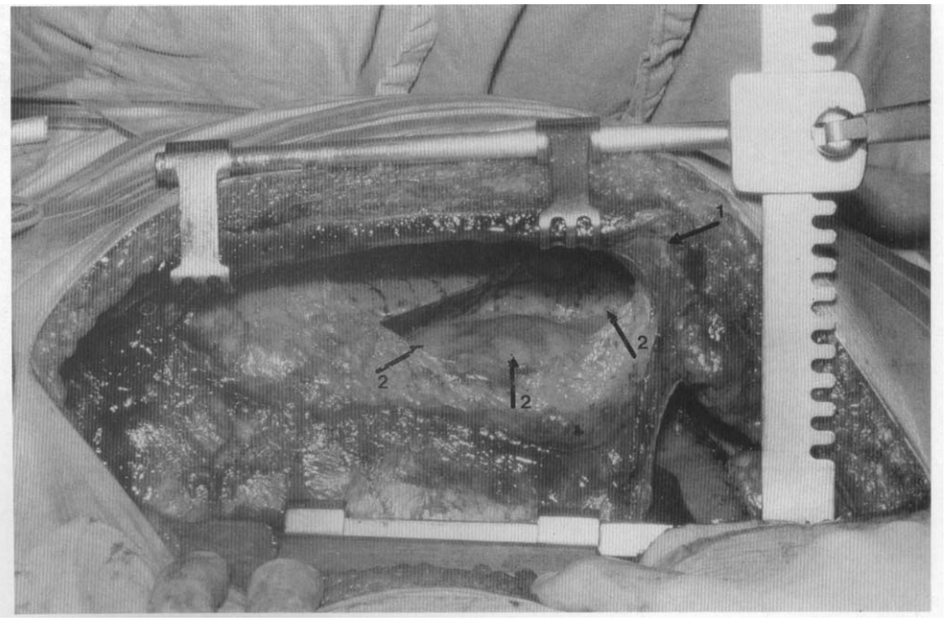


**3** In the presence of a significant diagonal artery, I would favor constructing a sequential D-LAD graft with LITA, to anastomose the free RITA to the Cx branch(es), and to reimplant the RITA graft into the LITA pedicle. The same principle applies if an ITA graft has to be used as a free graft because of injury at harvesting. In this configuration, even the distal branches of the RCA can be reached by the free RITA. Use of GEA becomes unnecessary, but one then has to rely on the sole LITA inflow for the whole myocardium.

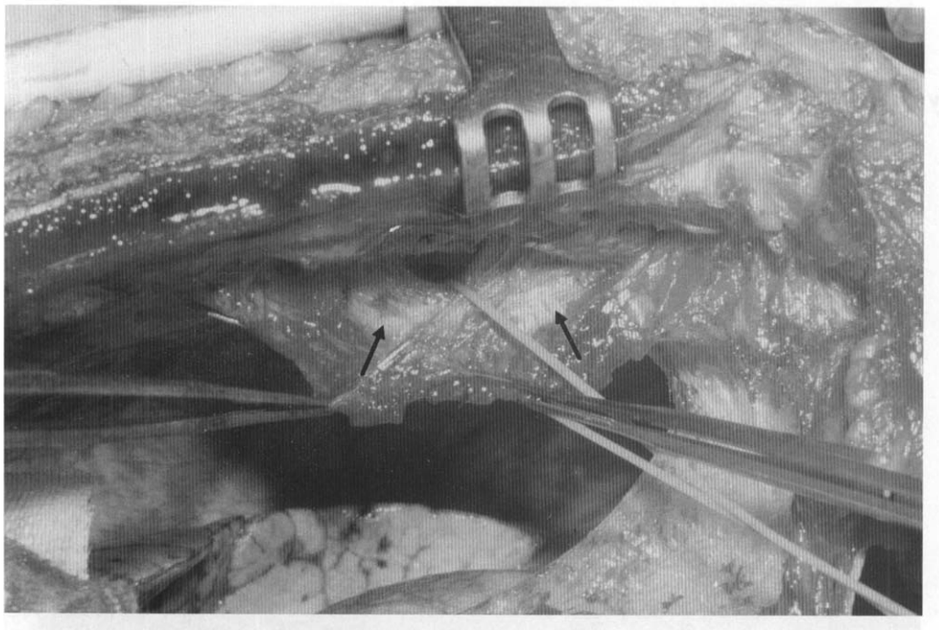
# SURGICAL TECHNIQUE

## Technique of ITA Harvesting

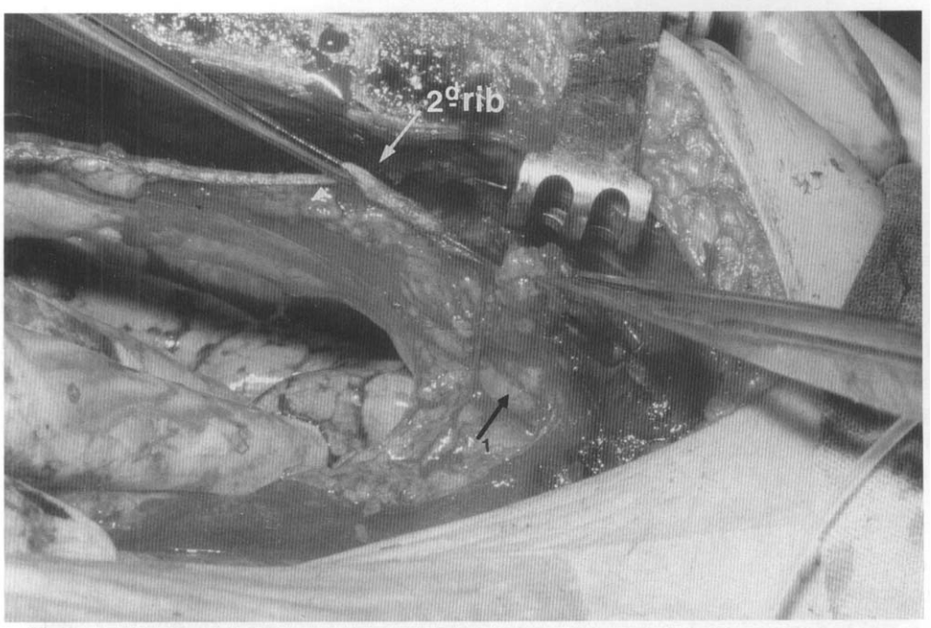
**4** The ITA Carpentier retractor (Delacroix, Chevalier, Paris) works on the principle of lifting and everting the sternal edge on the side of the ITA to be mobilized while depressing the opposite side. It can be readily transferred to the opposite side without the potential for wound contamination. Sternal retraction can be improved by dividing the attachment (arrow 1) of the diaphragm and of the rectus abdominis to its lower end. Pleurotomy (arrow 2) extends from the apex near the subclavian vein to the diaphragm.



**5** The outlines of the ITA (arrows) can be seen through the endothoracic fascia.



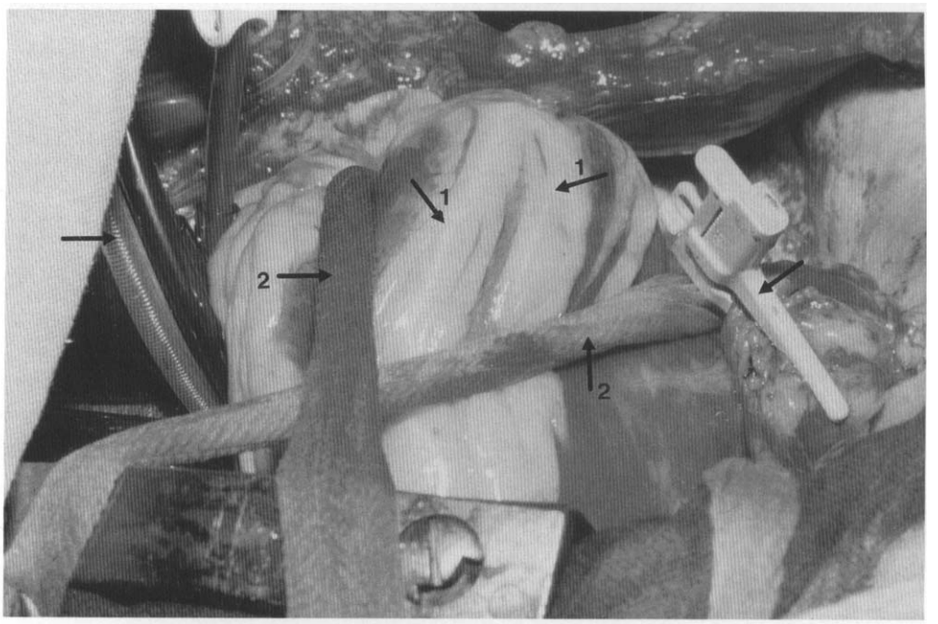
**6** Using low-power electrocautery and smooth-tipped forceps, the medial aspect of the endothoracic fascia is then incised, and the vascular pedicle (arrows) is peeled away from the costal cartilages at the level of the xyphoid. A vessel-loop can be passed around it and downward traction can be applied gently to facilitate the en-bloc dissection with about 1 to 2 cm of surrounding tissue.




**7** The final stage of dissection of RITA. The dissection is performed upward to the upper edge of the first rib, maintaining a downward traction with the vessel-loop or the surgeon's finger by using a combination of electrocautery and titanium clips (Weck, Pilling, Research Triangle Park, NC) for the larger side-branches. Care is taken to spare the first medial branch of the ITA, which usually serves as the major blood supply to the phrenic nerve.[28] The venous drainage of the ITA pedicle into the subclavian vein is usually preserved (arrow 1). The advantages of the en-bloc technique are its ease (particularly important in a teaching hospital with rotating trainees), the fact that mobilization can be carried out without handling the ITA directly, and that malrotation of the grafts can be easily prevented. After full heparinization (3 mg/kg), both ITA pedicles are divided distally, a soft bulldog clamp is applied, and the pedicles are infiltrated at a distance (high-pressure spray using a 22-gauge needle) with a papaverine solution (120 mg/100 mL normal saline) and stored between gauze patches soaked in the solution. Free cut-end flow is never measured at this stage because we consider it to be most unpredictive.

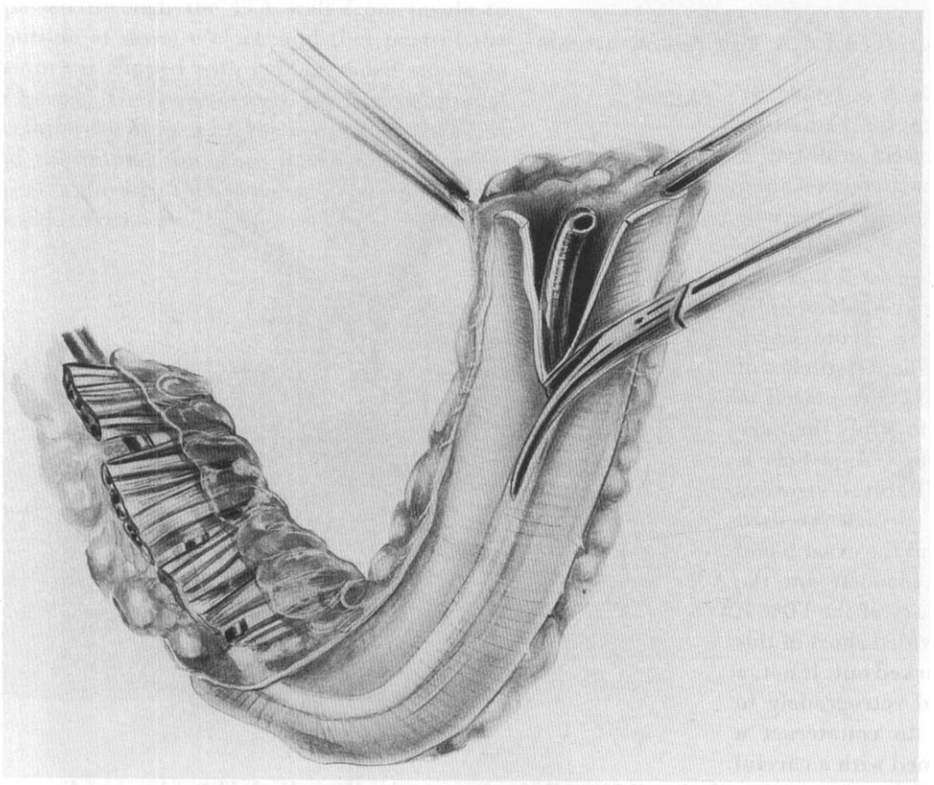
## Installation of Cardiopulmonary Bypass of Cardioplegy Delivery System of Retraction Slings

**8** After full heparinization and once all bypass material is harvested and preserved, cardiopulmonary bypass (CPB) is established through the cannulations of the ascending aorta ([DLP Medtronic DLP, Grand Rapids, MI] size 24 straight cannula [arterial cannula, 24 French straight tip, ⅜ in connection site, ref 75324, DLP] [arrow 1]) and of the right atrial appendage (DLP double-stage cannula [Two-stage venous cannula, 34 FR (French) × 48 FR, soft tip with ½ in connector site, ref 92348 TAC (cannula) 2, DLP] [arrow 2]). A Y-shaped vent (DLP) [Aortic root cannula, 12 GA (gauge) with vent line, ref 20012, DLP] is introduced into the ascending aorta at approximately 2 fingers breadth below the aortic cannula (arrow 3); one limb is intended to vent the left heart and the other one is intended to intermittently deliver cardioplegia. Two large slings (1 cm thick and 40 cm long) made of unfolded and twisted wet gauzes are then placed, one around the inferior vena cava (arrow 4) and one through the transverse sinus (arrow 5). These will allow for an easy and steady exposure of all aspects of the heart.



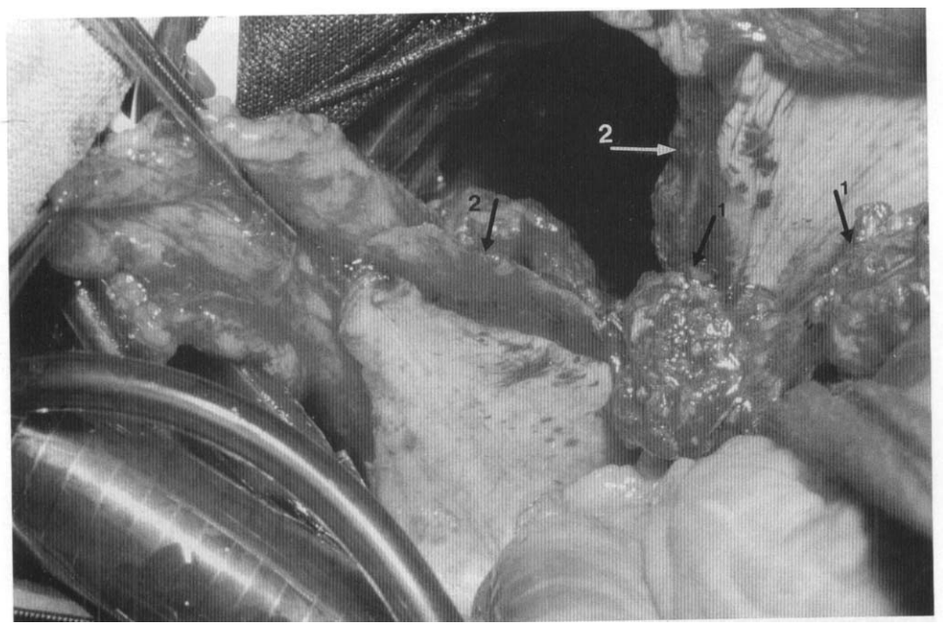

**9** Easy and steady exposure of the postero-lateral aspect of the heart and of the circumflex artery branches (arrows 1) by means of the two retraction slings (arrows 2). Other arrows feature a soft bulldog clamp on a GEA graft and the DLP retrograde coronary sinus cannula.

## Our Technique of Maximizing the IMA Length



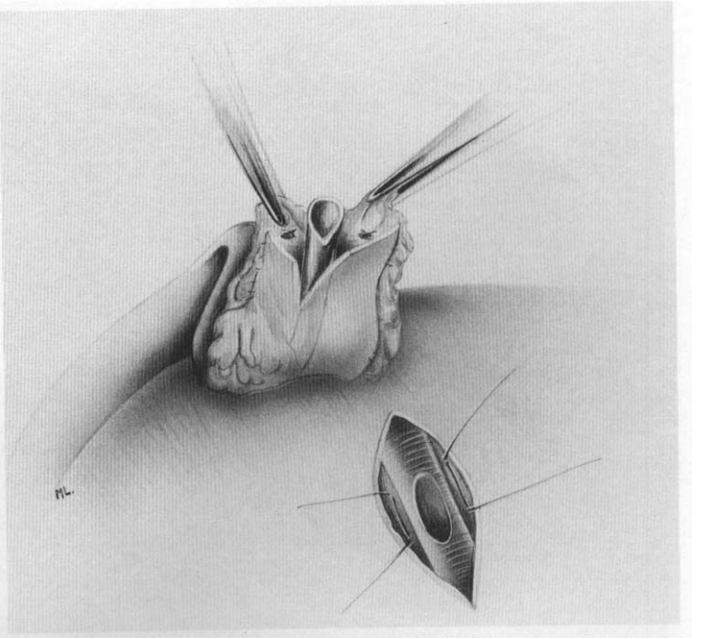
**10** We prefer a longitudinal incision in the ventral aspect of the pedicle onto the ITA itself, from the distal end up to the subclavian artery. The ITA vein can also be divided as it drains into the innominate vein. At the level of the first rib, the artery itself may be freed from all muscular and pleural attachments, taking care of respecting the first medial branch of the ITA and, of course, the phrenic nerve, which courses medial and posterior to the artery.

## Keep LITA Course as Short as Possible, Therefore, Under the Lung and Down to the Phrenic Nerve




**11** The longer the ITA pedicle, the smaller its distal caliber and the lower the distributed flow. Therefore, it is important to minimize the length of ITA between its origin from the subclavian artery and the first distal anastomosis. In our experience, we achieve this by opening the ipsilateral pleura (particularly on the left side) and by incising vertically the pleura and the pericardium down to the phrenic nerve. Arrows 1, LITA pedicle; arrows 2, deep vertical pleuro-pericardial incision.

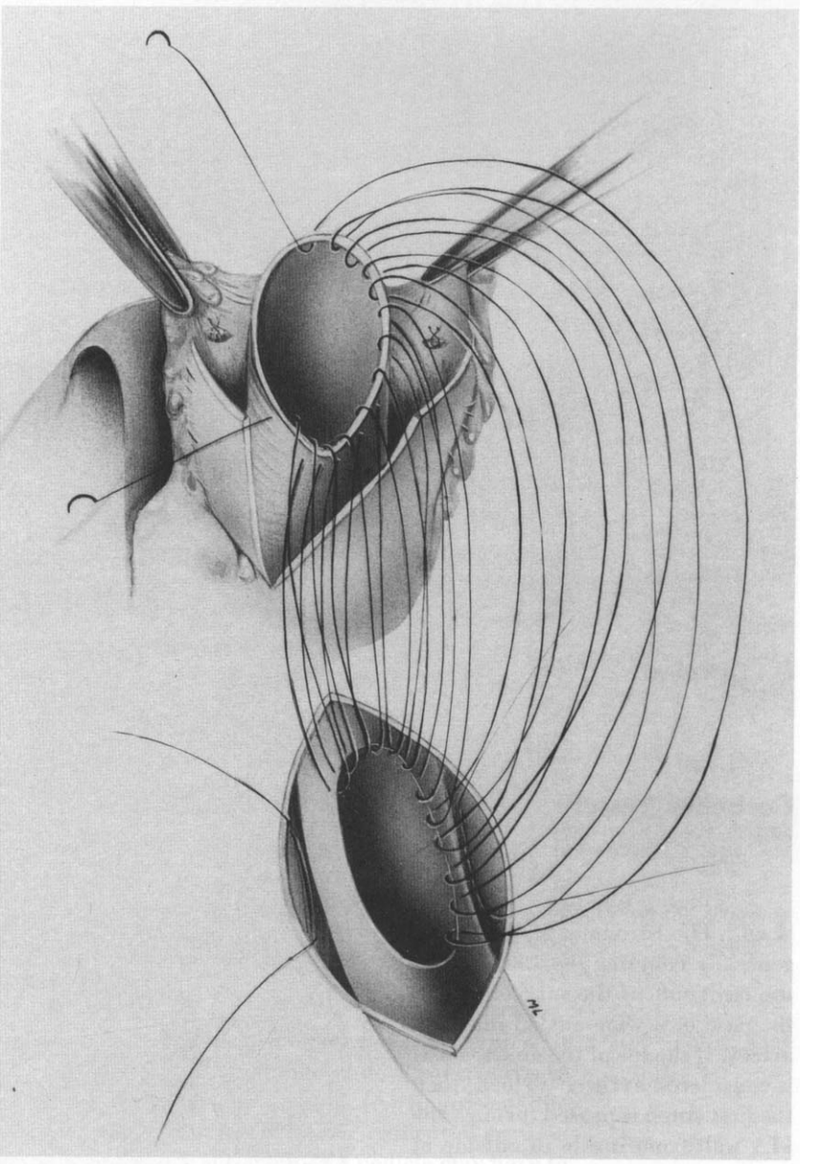
## Preparing the Coronary Vessel and ITA for the Anastomosis



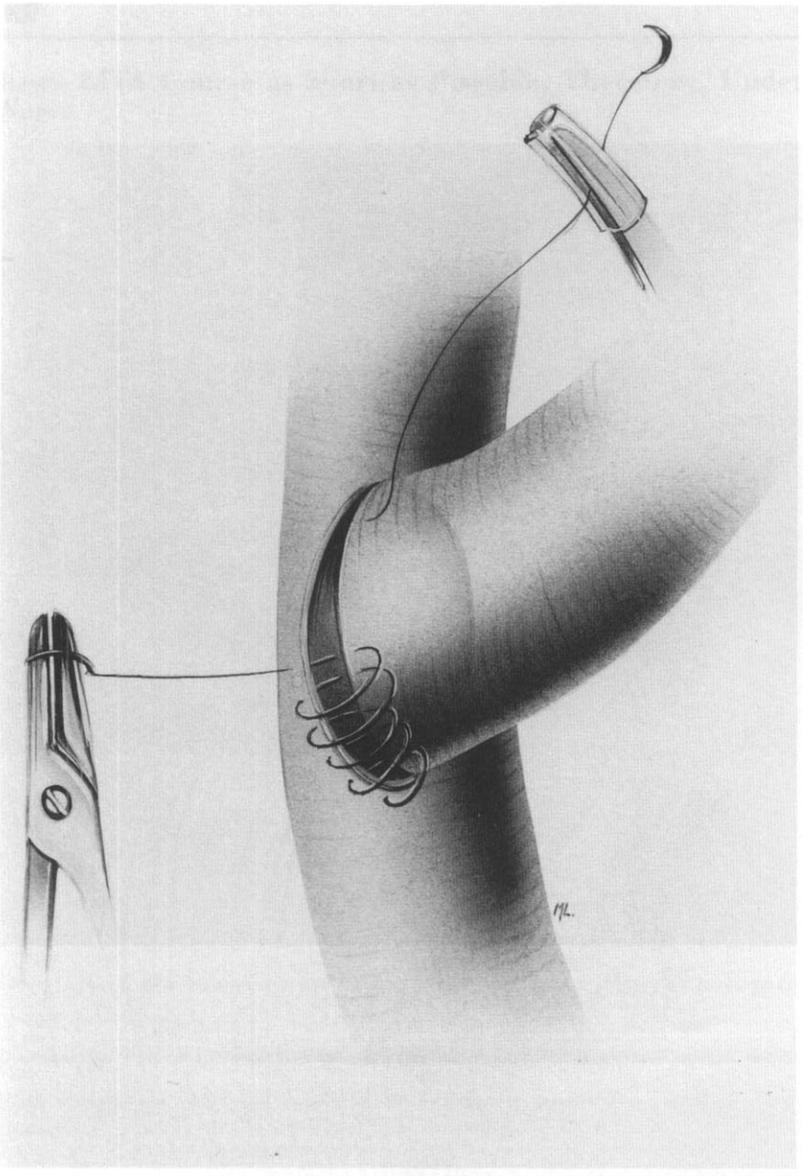
**12** Ideal exposure of the epicardium is obtained by appropriate disposition and traction on the retraction slings, which are then clipped to the towels to obtain a steady fixation (Fig 6). The site of the anastomosis is then selected, and the epicardium is gently incised longitudinally over the coronary vessel using a 15-bladed knife. The coronary vessel is then incised in length over 3 to 4 mm using a reversed 11-bladed knife or a Beaver blade knife (Eye blade, ref 5910, Becton Dickinson Acute Care, Franklin Lake, NJ). If necessary, two U-shaped stitches of Prolene 6/0 (Ethicon Inc., Somerville, NJ) are placed to recline the margins of a thick epicardium. Only then are the papaverine gauzes removed and the ITA pedicle is divided as short as possible. Almost invariably, a vigorous bloodstream is encountered, and the pedicle is used regardless of the vessel's distal caliber and the exact blood flow. In the (rare) presence of a sluggish bloodstream, the pedicle is inspected for an unnoticed injury of the ITA. If any injury is suspected, the pedicle is divided short of this lesion and another grafting strategy is worked out. If not, a 1 mm coronary dilator is gently passed retrogradely to exclude a significant ITA stenosis or to counteract a possible spasm. This can also be performed with a careful retrograde injection of a few milliliters of the papaverine solution (120 mg/100 mL normal saline). Both ITA veins are clipped. The mouth of the ITA artery is then evenly bevelled to a dimension of 4 to 5 mm in length (always somewhat longer than the coronary arteriotomy) using sharp-pointed microscissors while the assisting surgeon holds the ITA pedicle with two forceps. The ventral aspect of the pedicle is incised over 1 cm using Gerald scissors (Gerald-Reynolds, Aesculap, Germany). The parachute technique and a running stitch of 8/0 Prolene suture (0.4 metric, 18 in [45 cm], BV 130-5, 2 needles, ref. 8730) are used for all ITA anastomoses.

## Longitudinal Anastomoses

*Coronary Vessel Coursing Towards the Surgeon (Sagittal Plane)*



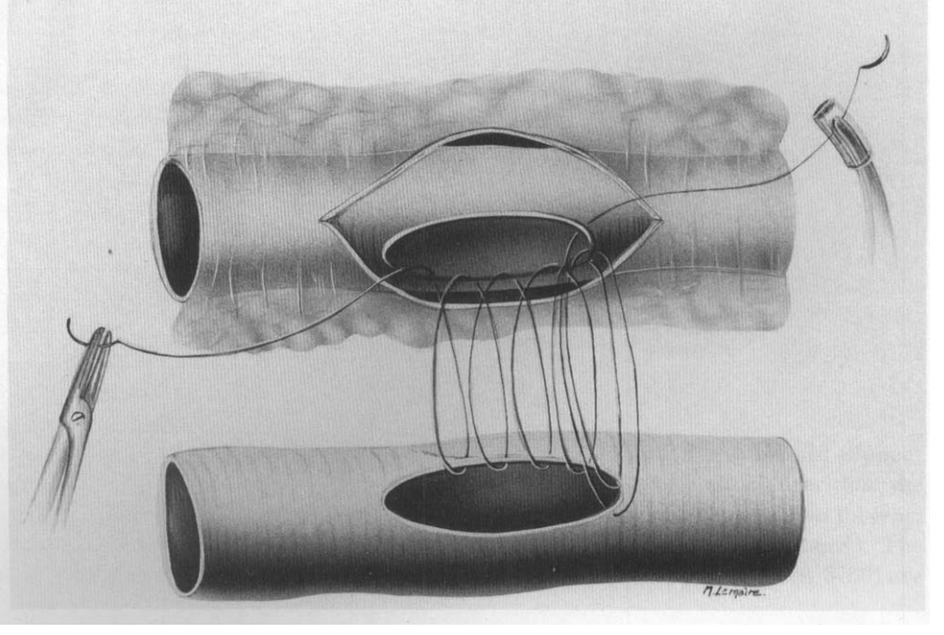
**13** If the heel of the anastomosis is considered at six o'clock, then the first stitch is passed through the ITA wall from inside to outside at seven o'clock and that part of the suture is clipped with rubber-shoed mosquito forceps. The anastomosis is then continued counterclockwise with the use of the other end of the suture, and care is taken to pass the needle through the coronary artery wall from inside to outside.

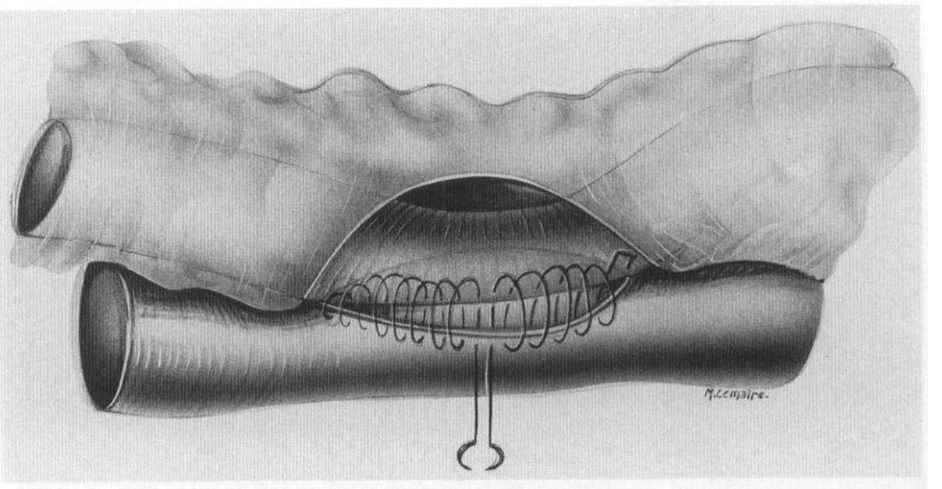


**14** When the toe of the anastomosis is reached, the ITA is brought down to the coronary vessel by gently pulling both ends of the suture, and the second half of the anastomosis is performed in situ. Therefore, the knot of the suture is situated at seven o'clock. Indeed, one should avoid placing a knot or a U-shaped stitch at the heel and/or on the toe of an anastomosis. Also, the spacing of the stitches should be considerably reduced at these two sites (at least three or four stitches). By respecting these rules, we have never detected a so-called purse-string effect in our angiographic restudies.

**Coronary Vessel Coursing in a Frontal Plane**

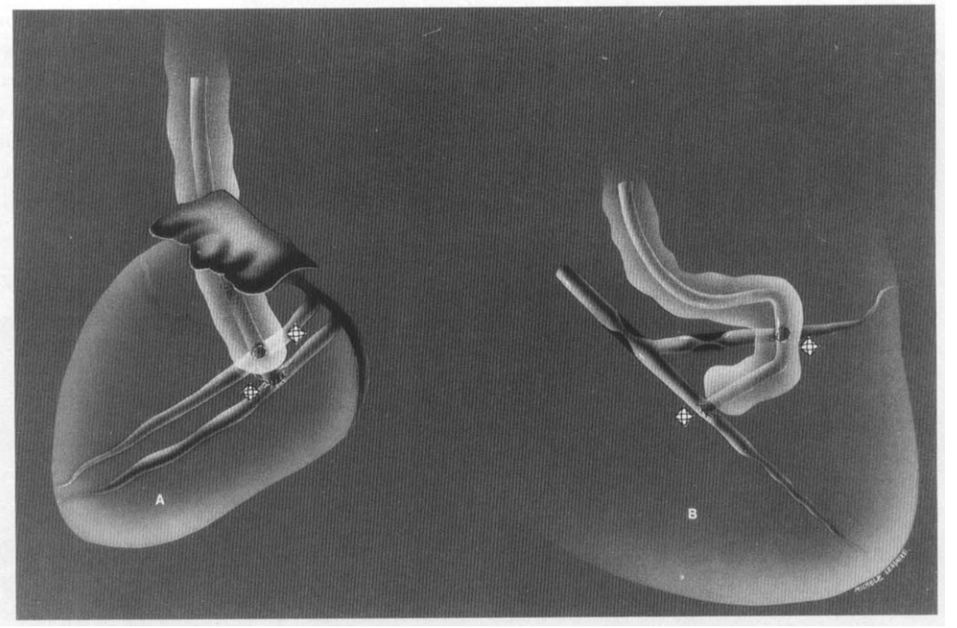
**15** The coronary vessel is then generally coursing from the left to the right side of the surgeon, ie, in the case of a wide-angled diagonal artery. If the toe of the anastomosis is considered at three o'clock, then the first stitch is passed through the ITA wall from inside to outside at two o'clock and then clipped with rubber-shoed mosquito forceps. The anastomosis is then continued clockwise using the other end of the suture, and care is taken to pass the needle through the coronary artery wall from inside to outside.





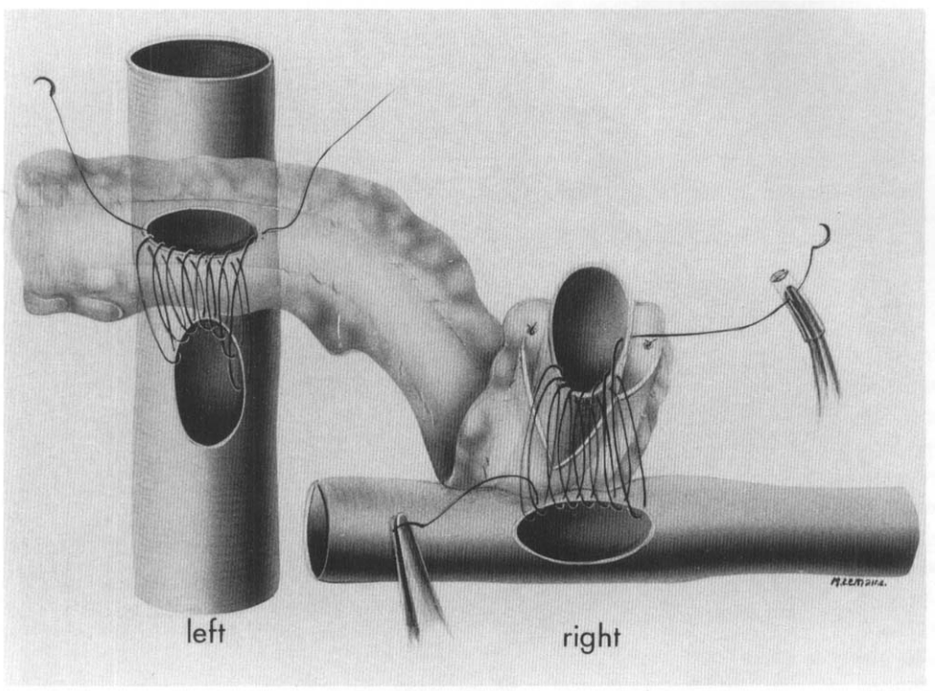
**16** When the heel of the anastomosis is reached, the ITA is brought down to the coronary vessel by gently pulling both ends of the suture. The running stitch is then continued until the midpoint between toe and heel is reached. The other needle is then used again and passed from outside to inside the ITA wall in a U-shaped fashion (arrow) at two o'clock; the anastomosis is then completed and the tie is placed at the midpoint of the lateral wall of the vessels.

## Diamond-Shaped Anastomoses

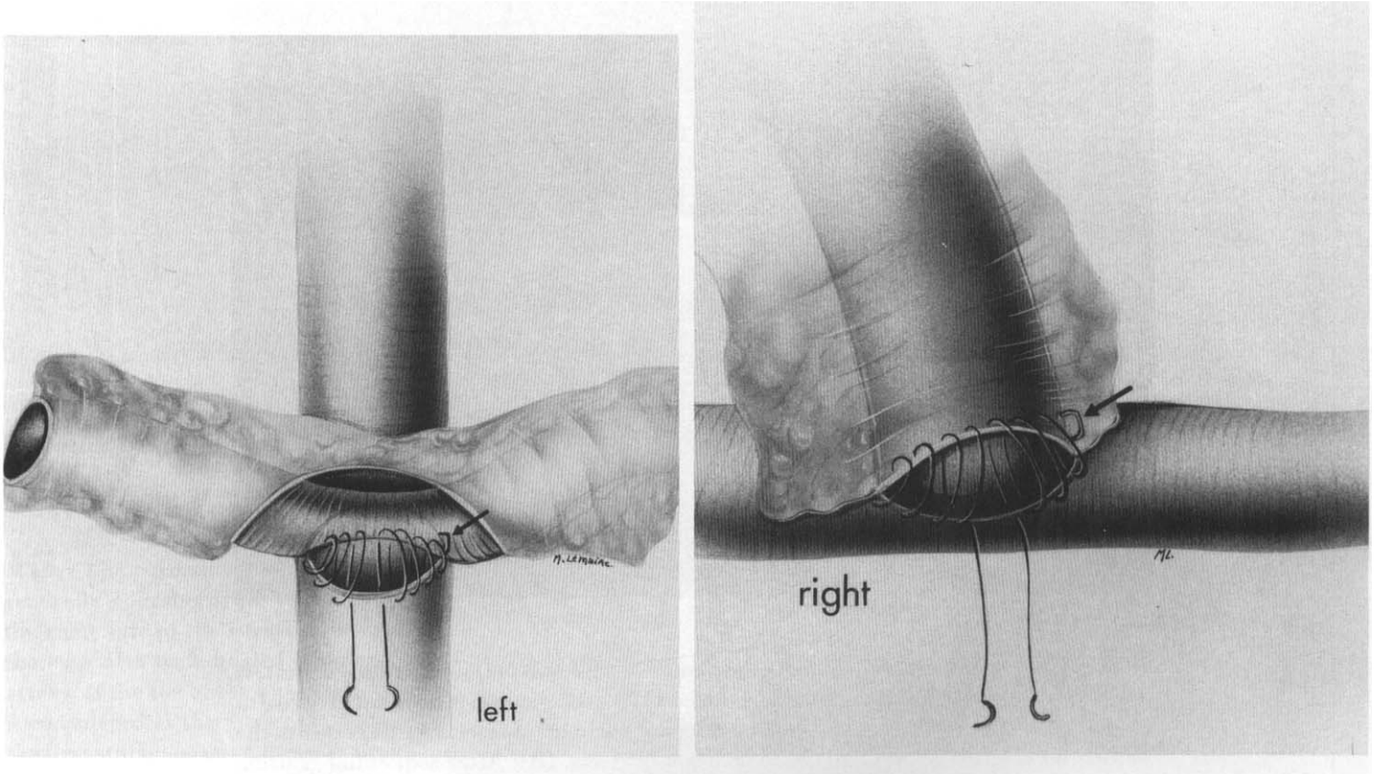



**17** The use of diamond-shaped anastomoses yields two major advantages: first, it helps to economize on the length of a pedicled ITA; and, second, it does not give rise to preferential flow towards the distal part of the coronary vessel. **(A)** Represents the sequential grafting of two circumflex marginal vessels. **(B):** After sequential grafting of one or more diagonal arteries (B), the extremity of the left ITA pedicle may have to be anastomosed to a somewhat distal segment of the LAD, whereas the stenosis of this vessel may be quite proximal. In this configuration, a T (diamond-shaped) anastomosis is preferred because it ensures equal perfusion of the LAD segments on each side of the anastomosis, whereas a longitudinal anastomosis might preferentially perfuse the smaller distal territory.

## Coronary Vessel Coursing Towards the Surgeon (Figs 18 Left and 19 Left) and Coursing in a Frontal Plane (Figs 18 Right and 19 Right)

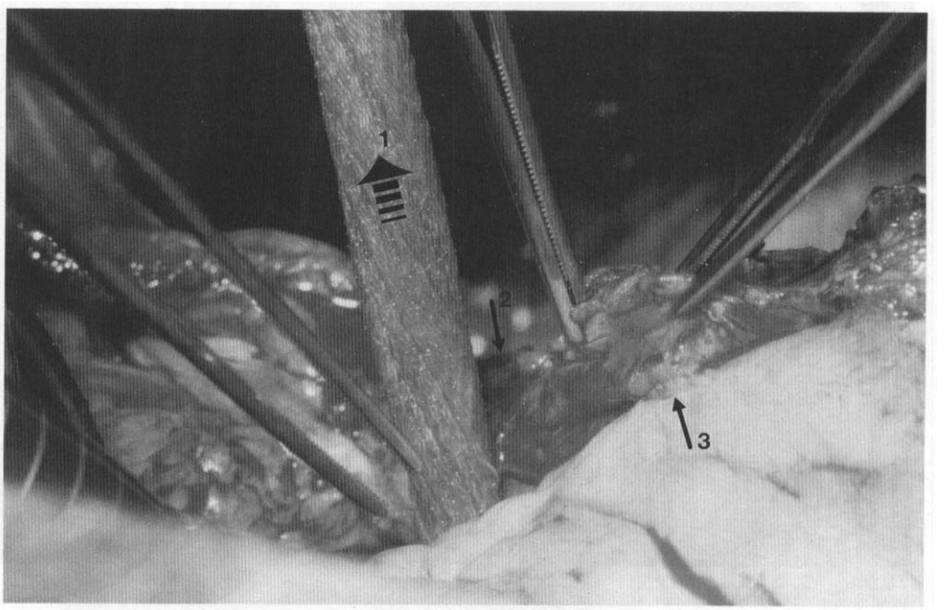



**18** (Left) The first stitch goes from outside to inside at the toe of the ITA arteriotomy, then from inside to outside at the midpoint of the right lateral wall of the coronary arteriotomy (three o'clock). The running suture continues clockwise on the ITA and counterclockwise on the coronary vessel toward the heel of the latter, and further to the opposite left lateral wall (nine o'clock). (Right) The first stitch goes outside to inside near the midpoint of the right lateral wall of the ITA arteriotomy (four o'clock), then from inside to outside just over the toe (two o'clock) of the coronary arteriotomy. The running suture continues clockwise on the ITA and counterclockwise on the coronary arteriotomy until the heel of the latter is reached.



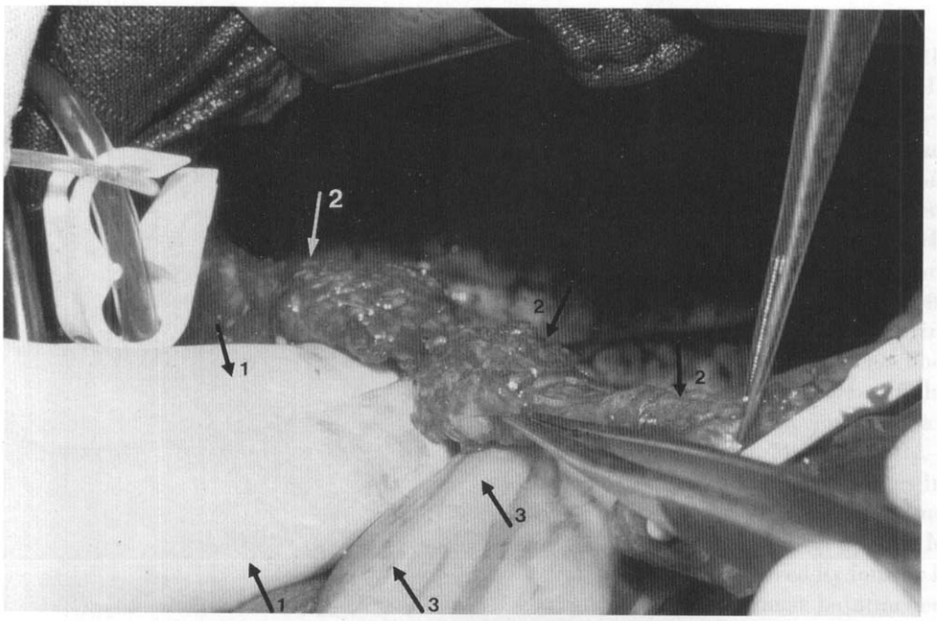

**19** (Left) The ITA is then brought down to the coronary vessel by pulling on both ends of the suture. The last half of the anastomosis is then completed counterclockwise, starting with a U-shaped stitch (outside-inside the ITA) (arrow) at three o'clock, well away from the inflow and outflow sites of the coronary arteriotomy. (Right) The ITA is brought down by pulling on both ends of the suture. The suture is then continued only as far as the midpoint between the toe and heel of the coronary arteriotomy. The other needle is then passed through the ITA wall from outside to inside at four o'clock (U-shaped stitch) (arrow), and the anastomosis is completed by a running suture towards the midpoint between the toe and heel of the coronary arteriotomy. The tie is thus placed at that midpoint, again, well away from the inflow and the outflow sites of the coronary arteriotomy. In side-to-side diamond-shape anastomoses, the length of the coronary arteriotomy should not exceed the diameter of the ITA to avoid flattening of the anastomotic site.

## LITA → D-LAD

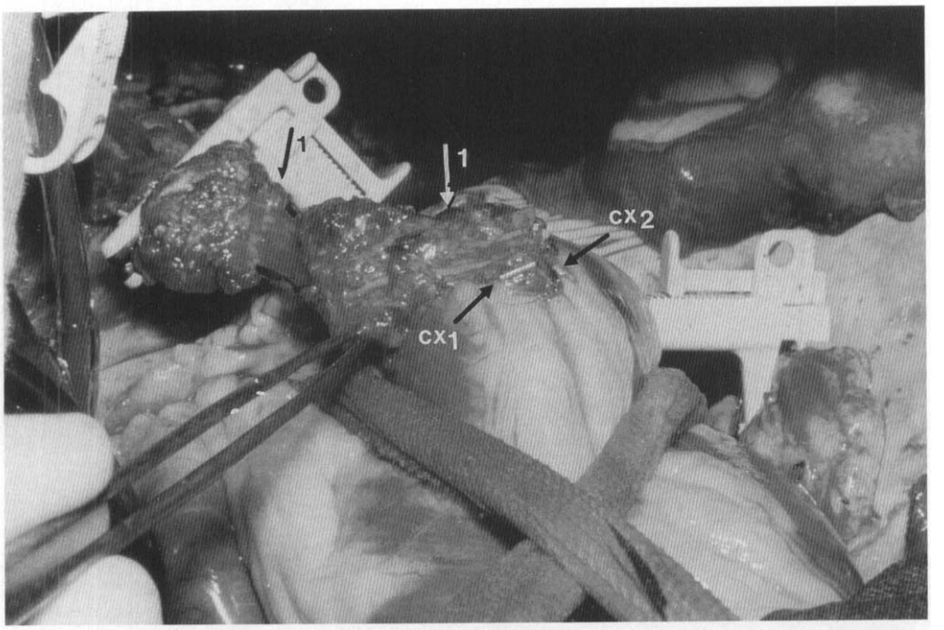



**20** The antero-lateral aspect of the left ventricle is lifted up and brought towards the surgeon in a horizontal plane by appropriate traction on the retraction slings (arrow 1). As explained previously, a deep vertical incision is made through the left mediastinal pleura and the pericardium down to the left phrenic nerve (Fig 11). Now LITA can be pulled straight (arrow 2) between its upper attachment and the anastomotic site (arrow 3) of the diagonal artery; when the heart is back in position, the ITA pedicle will regain an optimal length. However, in presence of severe lung emphysema, somewhat more ITA length must be provided. In the LAD area, I start with the most proximal side-to-side anastomosis. Indeed, the distance between the diagonal branches and the LAD will not increase with the filling of the heart because the graft then parallels the solid interventricular septum.

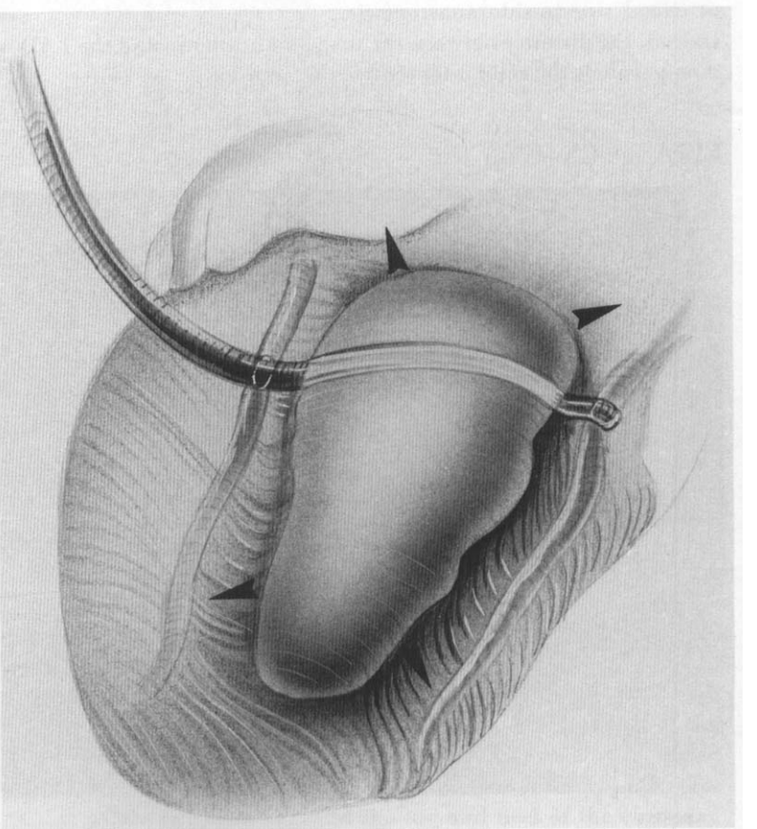
## LITA → CX-CX




**21** The postero-lateral aspect of the left ventricle is lifted up and rotated towards the surgeon in an oblique (near horizontal) plane by appropriate traction on the retraction slings (Fig 6). The maneuvre is facilitated by pushing the apex of the heart under the right sternal border. Vertical pleuro-pericardial incision is made down to the phrenic nerve as described previously (Fig 11). The surgeon places two fingers above the left atrial appendage (arrows 1), and LITA (arrows 2) is brought to the first circumflex anastomotic site (arrows 3), straight above these fingers.

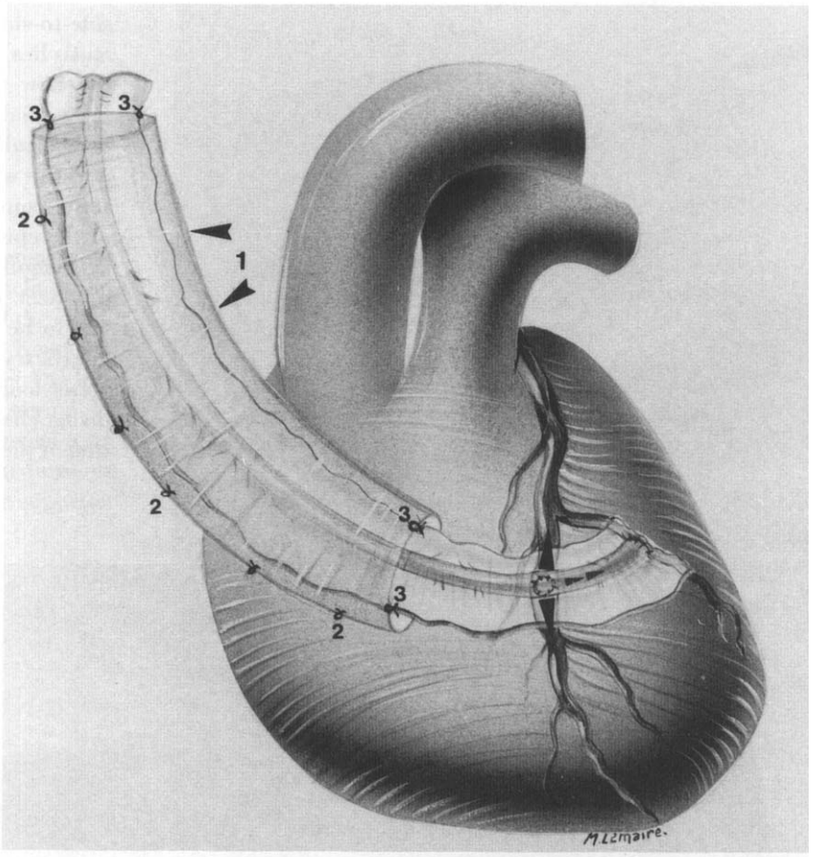



**22** In contrast with the LAD area, in the Cx area we usually first graft the most dominant vessel to be revascularized, even if it is the most distal one. After completion of that important anastomosis, we decide whether and in which sequence we anastomase the other one(s), taking into account the remaining length of the ITA pedicle, the level of the arteriotomy(ies) on the other vessel(s), and, last but not least, the potential increase of the heart diameter in the short axis after filling. Arrows 1, LITA; arrow Cx1, anastomosis LITA-Cx1; arrow Cx2, anastomosis LITA-Cx2.



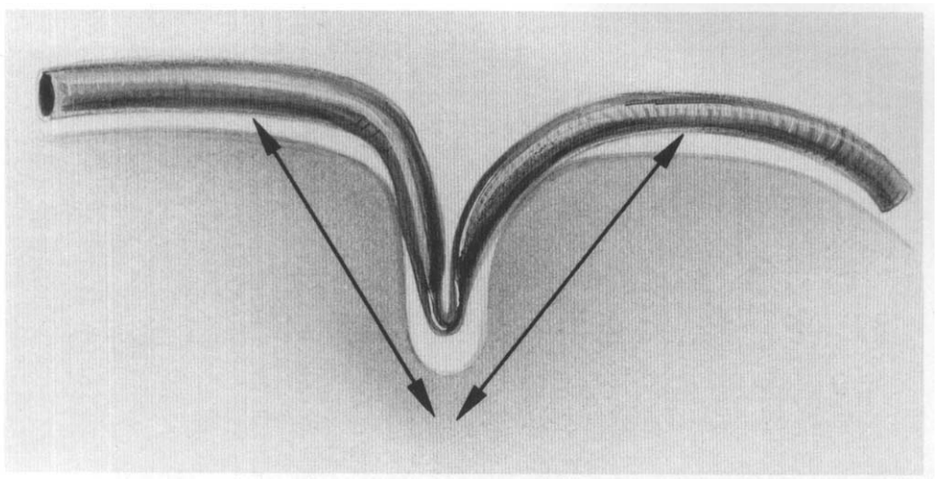
**23** I express a word of caution about constructing a sequential graft across an infarction scar, especially on the postero-lateral aspect of the left ventricle. The ITA segment, comprised between two anastomoses, can be distended and compressed by the bulge of the dyskinetic infarcted ventricular segment after the filling of the heart.

## RITA → LAD–Diagonal



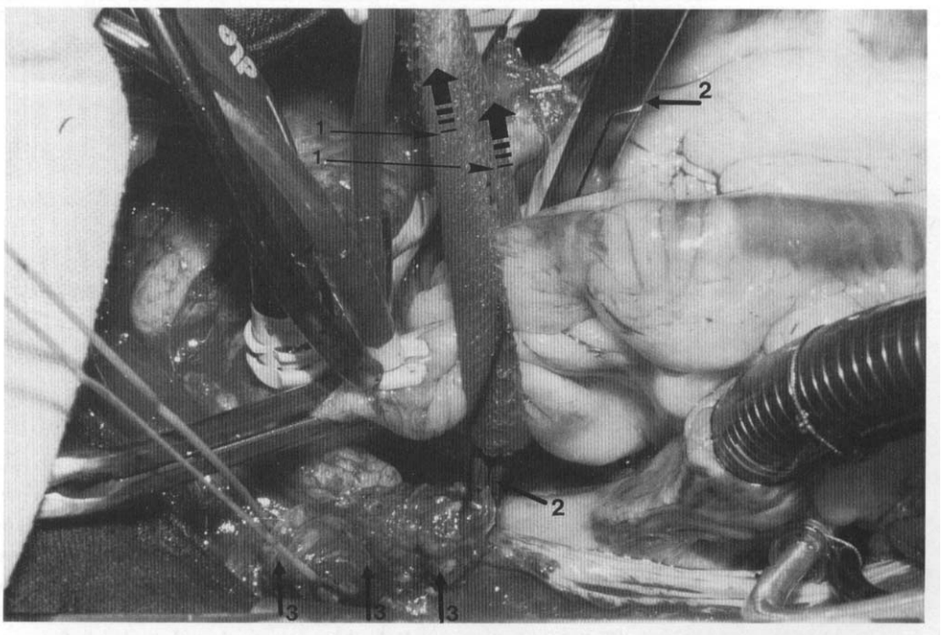

**24** I do not like constructing a sequential grafting RITA → LAD–Diagonal for three reasons: (1) LAD may steal the flow before it reaches diagonal (arrow steal); (2) the more proximal the LAD segment, the deeper into the epicardium, hence the danger of the seagull-wings effect of the side-to-side diamond-shaped anastomosis between RITA and LAD (Fig 25); and, (3) especially in the presence of cardiomegaly, the length of the RITA pedicle may be a source of concern, even more so if one wants to keep the RITA pedicle short of its distal bifurcation. When directed to the LAD area, the RITA pedicle must be protected from the sternum at the end of the procedure. This can be accomplished by resuturing the edges of the pleuropericardial flaps on top of the RITA pedicle. The maneuvre is greatly facilitated by an additional vertical incision of the pleura and pericardium on the right side, down to the superior vena cava. See Fig 11 for the left-sided pleuropericardial incision. More recently, a sleeve made of Goretex (Preclude IMA sleeve, WL Gore and Associates Inc., Flagstaff, AZ) has been used (arrows 1), not only to protect RITA, but also to allow easier identification at reoperation. The sleeve is opened longitudinally, passed around the pedicle, and loosely resutured by four or five stitches of polypropylene 4/0 (arrows 2). The sleeve must be attached to the right IMA pedicle at both ends (arrows 3) to avoid undesired interference with the distal anastomosis.

## The Seagull-Wings Kinking Effect: A Word of Caution

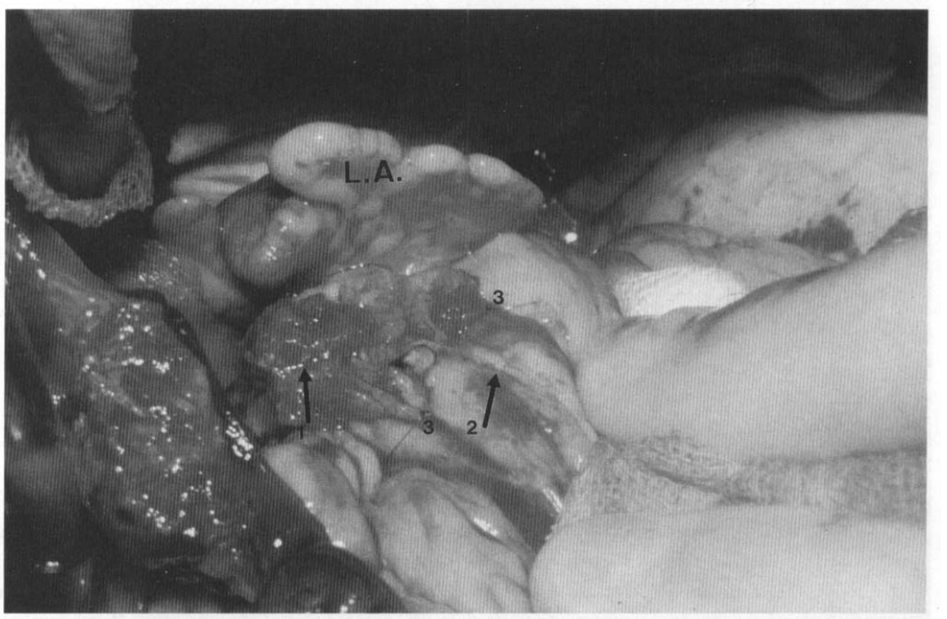


**25** If the anastomotic site of a side-to-side diamond-shape anastomosis lies deep into the epicardium, the flow to the distal part of the sequential graft is endangered by the seagull-wings kinking effect, especially when myocardium will resume contractions. If the margins of the epicardial crevice cannot be sufficiently erased (arrows), the prospect of that sequential graft has to be abandoned. Personally, I always try to approach that type of vessel longitudinally to decrease the diving effect and the sharp angulation of the graft.

## Bringing RITA Through the Transverse Sinus

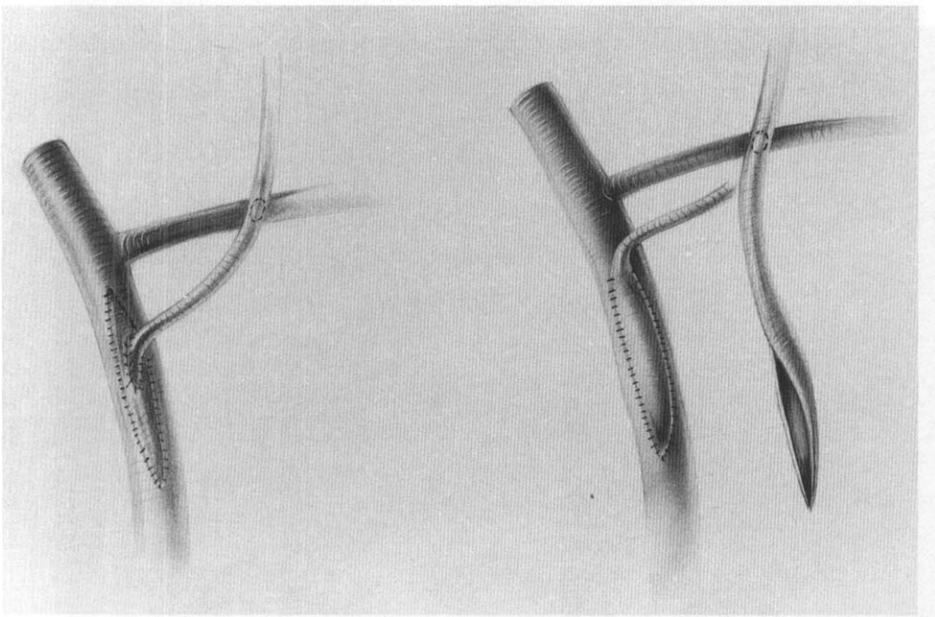



**26** First, always maximize RITA length (Fig 7) and divide RITA just short of its distal bifurcation. Check carefully for any bleeding spot on the RITA pedicle. Pull vertically on the upper retraction sling (arrows 1) (which is through the transverse sinus) and pass a large SEMB clamp (Aesculap FB961, Germany) (arrows 2) through the transverse sinus from the left to the right. Grab the RITA pedicle (arrows 3) with the SEMB clamp (arrows 2) and pull it through the transverse sinus. Apply a soft bulldog clamp on the RITA as proximally as possible. Lift up and rotate the postero-lateral aspect of the left ventricle towards the surgeon by means of the retraction slings as explained previously (Fig 6). Pull firmly on the RITA and put it under tension. If possible, shorten RITA to appropriate length. Bring the cranial (sternal) aspect of the ITA onto the epicardium, thus the ventral aspect is up.



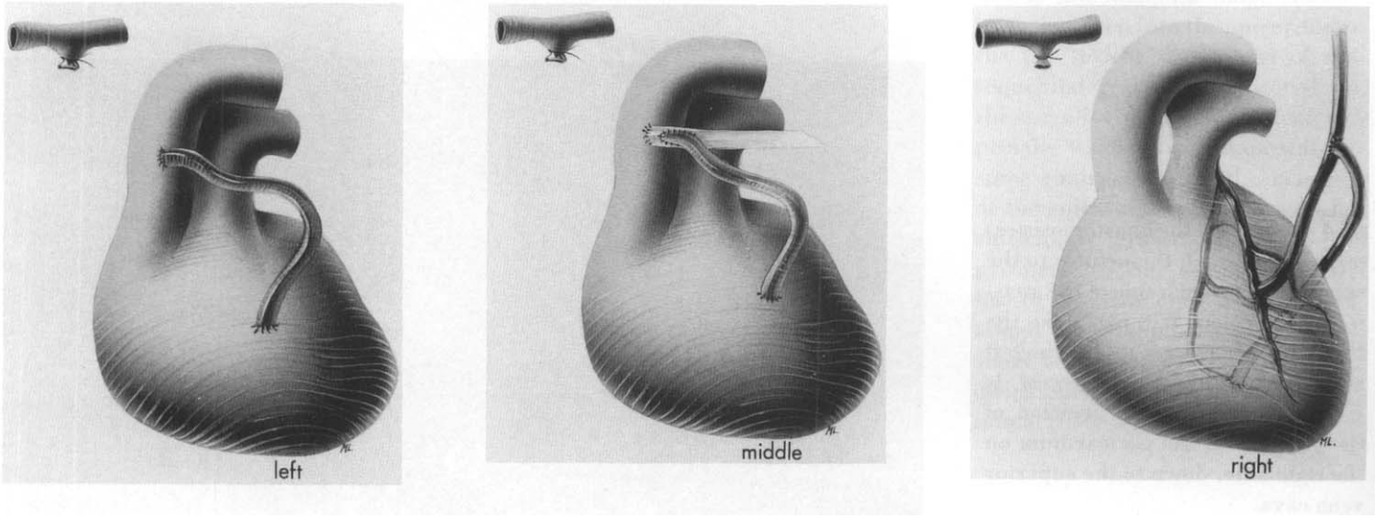

**27** Perform the anastomosis(es) (arrow 2). Attach the pedicle to the epicardium on each side of the anastomosis (Prolene 6/0) (3). Keep the RITA pedicle course under the left atrial appendage (LA). Arrow 1, RITA. Make a vertical incision of the pleura and the pericardium on the right side, down to the superior vena cava.

## Coronary Endarterectomy

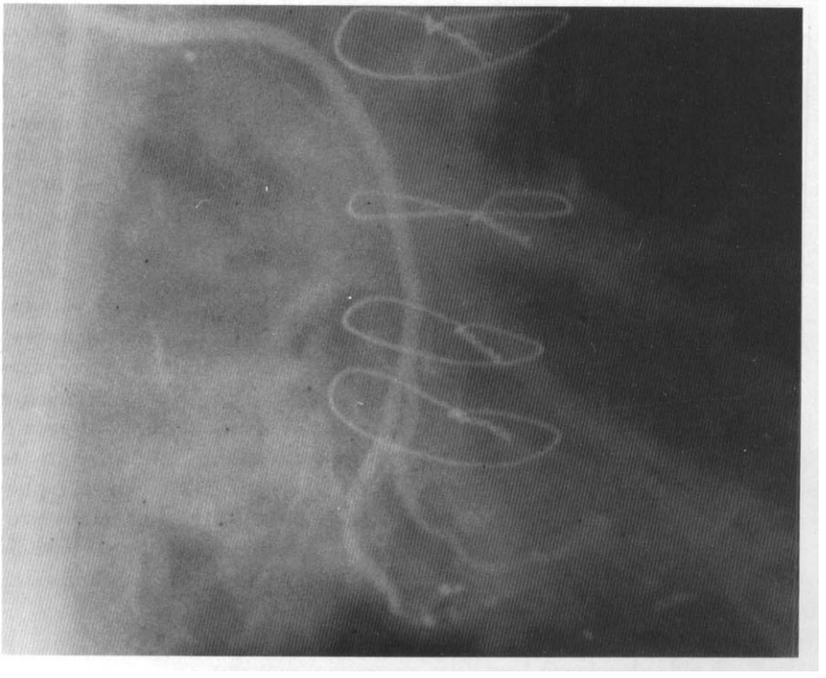


**28** In our experience, endarterectomy of the left coronary system is needed in approximately 3% of cases. A venous hood (left) is used to close the long coronary arteriotomy and the ITA is then implanted into it, as described previously.[29] This technique obviates the danger of flattening the narrow ITA over the broad coronary arteriotomy (right) after endarterectomy, permits an easy ITA anastomosis to the venous hood, and economizes on ITA length. Where extensive endarterectomy of the LAD area is required, we do not hesitate to supplement the ITA with a saphenous vein graft to immediately provide an optimal flow to the whole area of perfused myocardium.

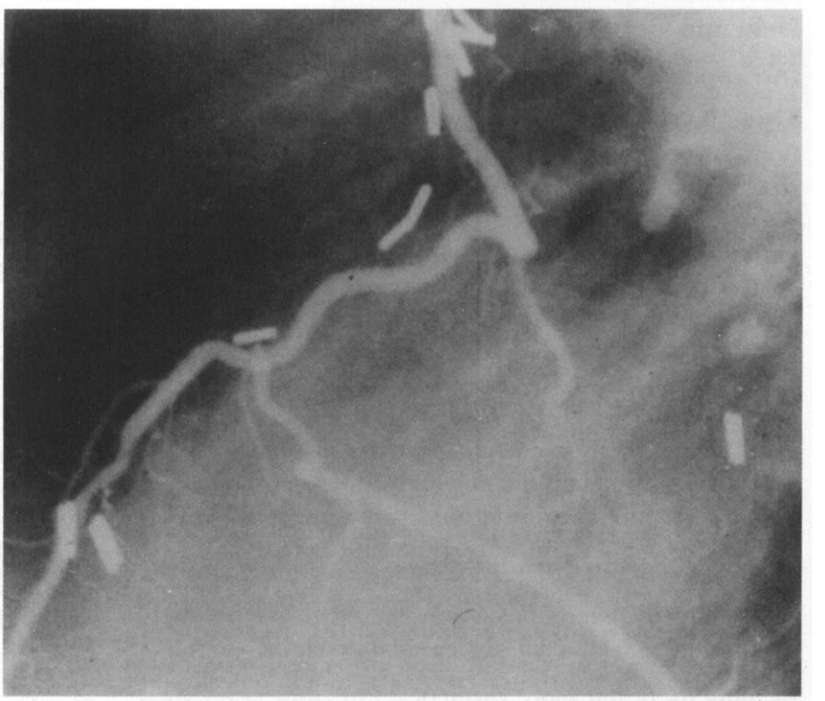
## Proximal Anastomoses of the Free ITA Grafts



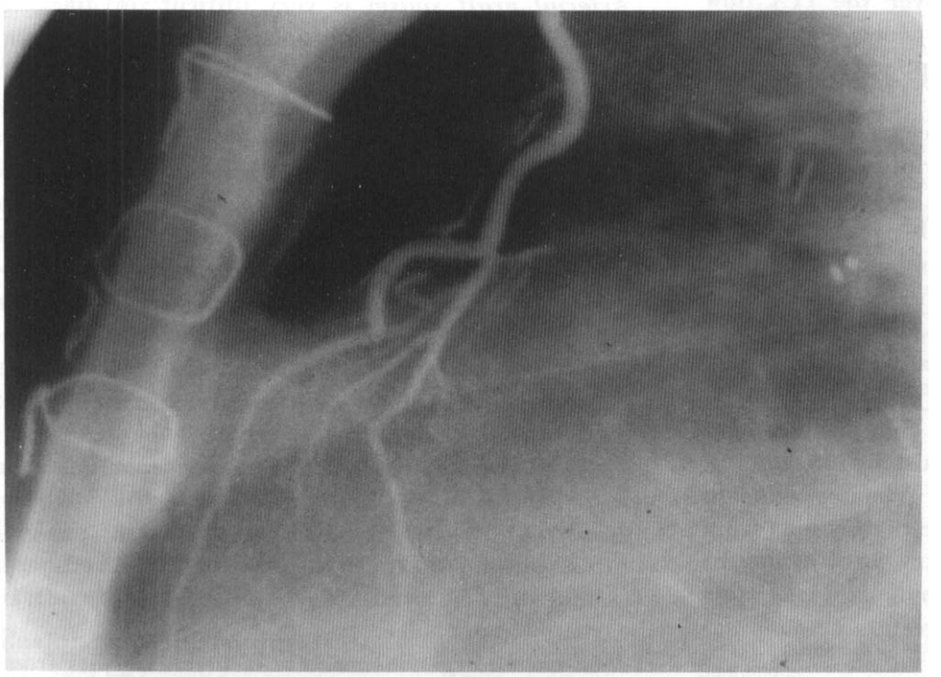

**29** (Left) Direct Ao-ITA suture; running suture of Prolene 7/0 (7/0 PROLENE [0.5 metric] M-8737, 24 in [60 cm], MS/2, BV 175-6, double needle; Ethalloy, Ethicon Inc., Somerville, NJ) (same stitching technique as for a longitudinal distal end-to-side anastomosis). (Middle) Via a venous hood or into the proximal part of a saphenous graft, running suture of Prolene 7/0. (Right) Anastomosis to the other ITA pedicle. To determine the optimal position and level of this important and delicate anastomosis, I prefer to construct it after performing the distal one(s). Running suture of Prolene 8/0 (8/0 PROLENE (0.4 metric), 18 in (45 cm), BV 130-5, two needles, ref 8730), longitudinal or diamond-shape, depending on the presentation (volume of the lungs and so on).



**30** RITA graft brought through the transverse sinus and sequentially anastomosed (diamond-shape fashion) to $Cx_2$ and $Cx_3$. Right anterior oblique view, 2 years postoperatively.



**31** Triple sequential LITA graft to two diagonal arteries and to the LAD. Left anterior oblique view, 6 months postoperatively. (Reprinted with permission.[19])



**32** Sequential LITA graft to one diagonal artery and to the LAD (diamond-shape T fashion). Left anterior oblique view, 2 years postoperatively.

## COMMENTS

In this section, some aspects that are specifically influenced by the use of arterial conduits will be focused on.[30]

### Ischemia

#### *Intraoperative Factors*

These factors include inadequate myocardial protection, incomplete revascularization, the ITA insufficiency syndrome, and reperfusion injury. The extensive use of pedicled arterial grafts may interfere with myocardial protection, particularly in evolving ischemia caused by the acute occlusion of a coronary vessel and in a reoperation when an old pedicled arterial graft has remained patent. Retrograde delivery of cardioplegia (and clamping the old patent arterial graft at reoperation) is then needed to achieve a homogeneous myocardial protection. In these instances, either we add an intermittent retrograde warm-blood cardioplegia to our normothermia technique or we revert to the cold crystalloid antegrade and retrograde cardioplegia.

Incomplete revascularization should never be tolerated and, if technical difficulties preclude complete revascularization with arterial grafts alone, one should not hesitate to add saphenous vein grafts.

As mentioned previously, whenever the ITA flow insufficiency syndrome[16,18,20,21] is suspected intraoperatively, we do not hesitate to add a saphenous-vein graft in parallel to a ITA graft. As a result of this strategy, we have practically eliminated the occurence of early postoperative hemodynamic deterioration, which is ascribed to that syndrome.

Angiographic restudy of these double grafts reveals a 88% patency rate of both the ITA and saphenous-vein grafts to the same vessel. Similar findings have been reported by Carrel et al.[21] We, like others,[2,3,5] believe that the ITA can maintain no-flow patency until saphenous-vein–graft failure occurs.

In our experience, the incidence of reperfusion injury has been minimized since the use of intermittent antegrade warm-blood cardioplegia. When reperfusion injury alone is suspected to preclude the weaning from cardiopulmonary bypass, we now try an injection of Nicardipine as a 5 mg bolus into the aortic root; this maneuvre has yielded spectacular results in some patients, as previously reported.[31]

#### *Postoperative Factors*

*Inadequate flow through arterial grafts.* As early as 1975, Flemma et al[32] showed that, initially, flow through the ITA is lower than through saphenous-vein grafts. Flow can even decrease in some hemodynamic conditions or if spasm occurs in the ITA.[33]

*Flow can be insufficient to meet metabolic requirements in some specific circumstances.* Experimental studies have shown a dramatic decrease in ITA flow in association with sudden hypovolemia and administration of high doses of nitrates. After induced hypovolemia, administration of epinephrine even decreased the ITA flow.[34] However, under normovolemic conditions, blood flow clearly paralleled changes in systolic blood pressure, and no deleterious effect of systemic vasoconstrictive agents was observed.

From these studies, it is clear that restoring normovolemia and maintaining an adequate driving pressure is of prime importance in maintaining satisfactory ITA flow. We have observed[30] the disappearance of ST segment changes after discontinuance of intravenous nitrates and administration of α-adregenic substances (norepinephrine); their effect on systemic blood pressure is probably more important than the direct vasoconstrictive action on the ITA.

In other cases, insertion of an intra-aortic balloon results in a dramatic improvement of the electrocardiogram changes; flow is enhanced by an increase in cardiac output, a raised diastolic pressure, and decreased coronary resistance caused by the reduction in myocardial wall stress.

*Arterial graft spasm* is very difficult to diagnose without performing angiography, which is, in turn, usually not allowed by the patient's condition. It must be suspected when acute ischemia of the corresponding myocardial area occurs, without apparent reason, after a period of hemodynamic and electrocardiographic stability.

Spasm can also occur in the native coronary arteries and, rarely, in saphenous-vein grafts.[35,36] The mechanisms involved in the pathogenesis of vascular spasm include decreased body temperature, release of vasoconstrictive substances by the platelets, increased blood *p* H, histamin release, and impaired release of endothelium-derived relaxing factor. Treatment consists of systemic administration of nitrates and/or calcium channel blockers.

If no response is observed in these various circumstances, additional saphenous grafting of the coronary vessel, already revascularized with the arterial graft, is the treatment of choice.

*Increased oxygen demand.* Ischemia results from an imbalance between myocardial oxygen supply and demand. Increased demand also can cause ischemia. This is especially true when patients awaken after surgery and are exposed to stress and pain.

Mangano et al[37] have shown that prolonged intensive

analgesia could significantly decrease ischemic episodes. In our experience,[30] administration of β-blockers has been found useful for decreasing catecholamine-induced increases in myocardial oxygen demand.

## Respiratory Problems

Several factors can cause lung injury, independent of whether arterial conduits have been used, such as trauma and hypoxic damage and inflammatory reaction to cardiopulmonary bypass. The extensive use of arterial grafts may be associated with longer CPB time. Harvesting of the ITA is frequently accompanied by pleural opening. Blood and fluid can induce atelectasis of the lower lobes, and pain related to chest drainage tubes can induce hypoventilation. The most effective means of reversing atelectasis is to provide ventilation with positive end-expiratory pressure and continuous positive airway pressure (CPAP) after extubation.

ITA grafting seems to be associated with a somewhat higher incidence of phrenic neuropathy that is probably associated with the technique of harvesting. Division of the small proximal pericardiophrenic artery can lead to ischemia of the phrenic nerve.[28] In our experience, phrenic-nerve palsy (most of the time reversible) occurs in 3% of patients benefiting from complex arterial grafting.

## Sternal Dehiscence

Blood is supplied to the sternum almost exclusively by branches of the ITA. Sternal ischemia is influenced by several factors, including the technique of harvesting and the position of the sternal wires. However, ischemia is only transient, and other factors, such as diabetes, obesity, advanced age, chronic obstructive pulmonary disease, the need for early resternotomy, chronic dialysis, and multiorgan failure, contribute to the development of sternal dehiscence and infection.

In our institution, the incidence of sternal complications in bilateral ITA grafting (2.5%) is increased two-fold in the presence of insulin-dependent diabetes and four-fold in patients undergoing chronic renal replacement therapy. We believe that any degree of sternal dehiscence, especially after bilateral ITA grafting, should be treated aggressively to prevent a secondary infection (0.4% in our series).

## Postoperative Bleeding

Bilateral ITA grafting has been reported to generate a greater incidence of excessive bleeding (up to 6%) when compared with saphenous-vein grafting or even with single ITA grafting.[38]

In our institution,[30] the transfusion requirements have decreased 10-fold over the last 8 years; the median number of exposures decreased from 10 units to 1 unit of allogenic blood products for the entire hospital stay because of improved and more expeditious surgical technique, intraoperative blood salvage, active intraoperative hemodilution, shorter extracorporeal circuit, low prime oxygenators, tranexamic acid or aprotinin, and the acceptance of lower hematocrit values in the immediate postoperative period (28%) and at discharge (33%). These results were obtained despite the fact that the average number of arterial distal anastomoses per patient rose over those years (2.2 to 3.1). Systemic normothermia during the surgical procedure also seems to decrease postoperative blood loss, such as that reported by Yau et al.[39]

## Results

Because the right gastroepiploic artery was preferred to RITA for grafting of the distal RCA and/or its branches, we have shown (Table 1) that pedicled RITA patency rates equal those of pedicled LITA (95.1 *v* 96.7), and that the localization of the grafted vessel (LAD, CX, RCA) does not significantly influence the patency rates of ITA anastomosis; (LAD *v* Cx *v* RCA were not significant).[22] In particular, bringing RITA across the anterior aspect of the heart to LAD, or even through the transverse sinus to Cx arteries, does not at all alter, in our experience, the patency rate of its distal anastomoses (Fig 30).

We have also shown in a previous report[19] that the patency rates of sequential ITA anastomoses (Fig 31) do not differ from those of single ITA anastomoses (95%) at a mean postoperative interval of 6 months (Table 2). Proximal anastomoses did somewhat better than distal ones (99% *v* 94%), but the difference was hardly

**TABLE 2. Angiographic Patency of IMA and Saphenous Grafts and Anastomoses 6 Months Postoperatively***

| | | Patent | | Intact | |
|---|---|---|---|---|---|
| Restudied | No. | No. | (%) | No. | (%) |
| IMA | | | | | |
| Grafts | 204 | 201 | 98.5 | 198 | 97 |
| Anastomoses | 383 | 364 | 95 | 356 | 93 |
| TEA excluded | 354 | 343 | 97 | 335 | 95 |
| Sequential grafts | 163 | 162 | 99.4 | 162 | 99.4 |
| Anastomoses | 342 | 325 | 95 | 321 | 94 |
| TEA excluded | 317 | 308 | 97 | 304 | 96 |
| Saphenous | | | | | |
| Grafts | 149 | 127 | 85.2 | 123 | 83 |
| Anastomoses | 338 | 289 | 85.5 | 284 | 84 |

*157/222 patients (71%). Thromboendarterectomy (TEA) excluded; excluding IMA grafts corresponding to at least one thromboendarterectomized vessel.

Reprinted with permission.[19]

significant and patency was more determined by the quality of the grafted coronary vessel. Also, ITA diamond-shaped anastomoses (Figs 30 and 32) patency rates (94.5%) did not differ significantly from the overall patency of the ITA anastomoses.

In a recent review of our first 124 free ITA grafts,[23] we have shown that their patency rates at 15 months were significantly lower than that of pedicled ITA grafts (86.4% *v* 100%, respectively). The type of proximal anastomosis (Fig 29) certainly played a role; the direct suture to the ascending aorta (with or without venous or pericardial hood) yielded a 82.8% patency rate, whereas the anastomosis to the proximal segment of a saphenous vein or to the other ITA graft resulted in a 89.7% patency rate. However, we suspect that the proximal anastomosis was not the only factor responsible for this early atrition. Indeed, the ascending aorta is probably the least suitable part of the entire arterial system to receive a graft. The ascent of the systolic head of pressure (dp/dt) is there the highest and corresponds with the peak of coronary resistance during systoly. This situation may favor disruption of the endothelium and the internal elastic lamina of free grafts and result in early intimal hyperplasia. We then try to restrict the use of free grafts and, if we have no alternative, we now anastomose them to the other pedicled ITA (Figs 10 and 29 [right]), as reported by Tector et al,[24] Barra et al,[25] and Calafiore et al.[26]

The results of quantitative angiographic studies[40] support the concept of a more efficient endothelium-dependent control of vasomotor tone, possibly contributing to the favorable long-term functional results of ITA grafts. They also show the adaptability of ITAs to chronic and to acute changes in blood-flow requirements, resulting both from growth potential and from vasomotor properties.

## ACKNOWLEDGEMENT

The author is deeply indebted to Mrs Michèle Lemaire for her invaluable artwork, to Mr Johnny Fets for the intra-operative photographs, and to Mrs Monique Dits and Eliane Debecker for their precious secretarial assistance.

## REFERENCES

1. Green GE, Stertzer SH, Reppert EH: Coronary arterial bypass grafts. Ann Thorac Surg 5:443-450, 1968
2. Aris A, Barras X, Ramio J: Patency of internal mammary artery grafts in no-flow situations. J Cardiovasc Surg 93:62-64, 1987
3. Dincer B, Barner HB: The "occluded" internal mammary artery graft: Restoration of patency after apparent occlusion associated with progression of coronary disease. J Thorac Surg 85:318-320, 1983
4. Hanet C, Wyns W, Decoster O, et al: Angiographic evaluation of vasomotor properties of internal mammary arteries before and after coronary artery bypass grafting in men. Am J Cardiol 65:918-921, 1990
5. Kitamura S, Kawachi K, Seki T, et al: Angiographic demonstration of no-flow anatomical patency of internal thoracic-coronary artery bypass grafts. Ann Thorac Surg 53:156-159, 1992
6. Singh RN, Berg RA, Kay EB: Physiological adaptability: The secret of success of the internal mammary artery grafts. Ann Thorac Surg 41:247-250, 1986
7. Schoeffter PH, Dion R, Godfraind T: Modulatory role of the vascular endothelium in the contractility of human isolated internal mammary artery. Br J Pharmacol 95:531-543, 1988
8. Chaikhouni A, Crawford FA, Kochel PJ, et al: Human internal mammary artery produces more prostacyclin than the saphenous vein. J Thorac Cardiovasc Surg 92:88-91, 1986
9. Sims FH: The internal mammary artery as a bypass graft? Ann Thorac Surg 44:2-3, 1987
10. Van Son JAM, Smedts J, Vincent GJ, et al: Comparative anatomic studies of various arterial conduits for myocardial revascularization. J Thorac Cardiovasc Surg 99:703-707, 1990
11. Galbut DL, Traad EA, Dorman MJ, et al: Seventeen-year experience with bilateral internal mammary artery grafts. Ann Thorac Surg 49:195-201, 1990
12. Fiore AC, Naunheim KS, Dean PH, et al: Results of internal thoracic artery grafting over 15 years: Single versus double grafts. Ann Thor Surg 49:202-209, 1990
13. Grondin CM, Campeau L, Lespérance J, et al: Comparison of late changes in internal mammary artery and saphenous vein grafts in two consecutive series of patients 10 years after operation. Circulation 70:1208-1213, 1984
14. Barner HB, Barnett MG: Fifteen- to twenty-one-year angiographic assessment of internal thoracic artery as a bypass conduit. Ann Thorac Surg 57:1526-1528, 1994
15. Puig IB, Neto LF, Rati M: A technique of anastomosis of the right internal mammary artery to the circumflex artery and its branches. Ann Thorac Surg 38:533-534, 1984
16. Jones EL, Lattouf O, Lutz JF, et al: Important anatomical and physiological considerations in performance of complex mammary-coronary artery operations. Ann Thorac Surg 43:469-477, 1987
17. Rankin JS, Newman GE, Bashore TM: Clinical angiographic assessment of complex mammary artery bypass grafting. J Thorac Cardiovasc Surg 92:832-846, 1986
18. Von Segesser LK: Arterial grafting for myocardial revascularization. New York, NY, Springer, 1990, pp 48-52
19. Dion RAE, Verhelst R, Rousseau M, et al: Sequential mammary artery grafting: Clinical, functional and angiographic assessment 6 months postoperatively in 231 consecutive patients. J Thorac Cardiovasc Surg 98:80-89, 1989
20. Sarabu MR, McClung JA, Fass A, et al: Early postoperative spasm in left internal mammary artery bypass grafts. Ann Thorac Surg 44:199-200, 1987
21. Carrel T, Kujawski T, Zünd G, et al: The internal mammary artery malperfusion syndrome: Incidence, treatment and angiographic verification. Eur J Cardiothorac Surg 9:190-197, 1995
22. Dion R, Etienne PY, Verhelst R, et al: Bilateral mammary grafting. Clinical, functional and angiographic assessment in 400 consecutive patients. Eur J Cardiothorac Surg 7:287-294, 1993
23. Verhelst R, Etienne PY, El Khoury G, et al: Free internal mammary artery graft in myocardial revascularization. Cardiovasc Surg 4:212-216, 1996
24. Tector AJ, Amundsen S, Schmahl TM, et al: Total revascularization with T grafts. Ann Thorac Surg 57:33-39, 1994
25. Barra JA, Bezon E, Mansourati J, et al: Reimplantation of the right internal thoracic artery as a free graft into the left in situ internal thoracic artery (Y procedure). One-year angiographic results. J Thorac Cardiovasc Surg 109:1042-1048, 1995
26. Calafiore AM, Di Giammarco G, Luciani N, et al: Composite arterial conduits for a wider arterial myocardial revascularization. Ann Thorac Surg 58:185-190, 1994
27. Calafiore AM, Teodori G, Mezzetti A, et al: Intermittent antegrade warm blood cardioplegia. Ann Thorac Surg 59:398-402, 1995

28. O'Brien JW, Johnson SH, VanSteyn SJ, et al: Effects of internal mammary artery dissection on phrenic nerve perfusion and function. Ann Thorac Surg 52:182-188, 1992
29. Dion RAE, Noirhomme P, Wyns W, et al: Left-sided coronary thromboendarterectomy in complex internal mammary artery grafting, in Ghosch PR, Unger F (eds): Cardiac Reconstructions. Berlin, Germany, Springer, 1989, pp 319-326
30. Jacquet L, Goenen M, Baele PH, et al: Postoperative management, in Angelini GD, Bryan AJ, Dion R (eds): Arterial Conduits in Myocardial Revascularization. London, United Kingdom, Arnold, 1996, pp 153-162
31. Amrani M, Matta A, Dion RA: Beneficial effect of nicardipine on perioperative myocardial ischemia. Ann Thorac Surg 55:813-814, 1993
32. Flemma RJ, Singh HM, Tector AJ, et al: Comparative hemodynamic properties of vein and mammary artery in coronary bypass operations. Ann Thorac Surg 20:619-627, 1975
33. Loop FD, Thomas JD: Hypoperfusion after arterial bypass grafting. Ann Thorac Surg 56:812-813, 1993
34. von Segesser LK, Lehman K, Turina M: Deleterious effects of shock in internal mammary artery anastomoses. Ann Thorac Surg 47:575-579, 1989
35. Nijsen-Karelse M, Dion RAE, Jambroes G: Nifedipine in cardiac operations. J Thorac Cardiovasc Surg 84:145, 1982
36. Zeff RJ, Iannone LA, Kongtahworn C, et al: Coronary artery spasm following coronary artery revascularization. Ann Thorac Surg 34:196-199, 1982
37. Mangano DT, Siciliano D, Hollenberg M, et al: Postoperative myocardial ischemia. Therapeutic trials using intensive analgesia following surgery. Anesthesiology 76:331-333, 1992
38. Kouchoukos NT, Wareing TH, Murphy SF, et al: Risks of bilateral internal mammary artery bypass grafting. Ann Thorac Surg 49:210-219, 1990
39. Yau TM, Carson S, Weisel RD, et al: The effect of warm heart surgery on postoperative bleeding. J Thorac Cardiovasc Surg 103:1155-1163, 1992
40. Hanet C, Dion R: Detection of ITA graft function and patency, in Angelini GD, Bryan AL, Dion R (eds): Arterial Conduits in Myocardial Revascularization. London, United Kingdom, Arnold, 1996, pp 78-85

From the Department of Thoracic and Cardiovascular Surgery, Cliniques Universitaires St-Luc, Université Catholique de Louvain, Brussels, Belgium.

Address reprint requests to Professor Robert Dion, MD, Cliniques Universitaires St-Luc, Department of Thoracic and Cardiovascular Surgery, avenue Hippocrate 10, B-1200 Brussels, Belgium.



1085-5637/96/0102-0001$5.00/0